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## Technical Report

No. 13542

Development Of A Kit To Reduce  
The Noise Level Of The MOST Vehicle

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**DEVELOPMENT OF A KIT TO REDUCE  
THE NOISE LEVEL OF THE MOST VEHICLE**

**Submitted By**

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## **EXECUTIVE SUMMARY**

The Keweenaw Research Center (KRC) was contracted by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and the U.S. Army Tank-Automotive Command (TACOM) to develop a kit to reduce the noise signature of the Mobile Over Snow Transport (MOST) System, using current "off-the-shelf" items. Together with a literature search, manufacturing information search and field tests a kit was developed that reduced noise levels by 10 dBC or more, after subtracting off wind noise. Several suggestions are recommended including a proposed follow-on study to further reduce noise levels emitted from the MOST vehicle.



## **Introduction**

The Mobile Over Snow Transport (MOST) system will provide Special Forces (SF) an increased capability, through organic mobility, to conduct unconventional warfare, strike and perform strategic intelligence operations in basic cold and severe cold environments. This will allow SF to infiltrate/exfiltrate areas and navigate over long distances with enough subsistence and equipment to perform the mission with an increased probability of survival. The MOST will be used by SF in a clandestine role performing operations before, during and after the declaration of hostilities and during training missions. The MOST will be used in extremely deep battle fronts to allow SF to provide strategic intelligence and strike/interdiction missions as directed by the Theater Commander for National Command Authority for periods up to 30 days. The MOST will be used to conduct missions primarily during limited visibility or darkness.

The MOST is a two component system consisting of a small, fast over snow vehicle (snowmobile) and a sled/ahkio to be used by the SF.

The Keweenaw Research Center (KRC), a research agency of Michigan Technological University (MTU), was contracted by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) and the U.S. Army Tank-Automotive Command (TACOM) to perform tests on government furnished snowmobiles and to develop a kit, using current off-the-shelf items and technology to reduce the noise level and acoustic signature of the MOST vehicle. This was done with the intent that the machines can be operated with a low probability of detection.

The noise kit was developed to replace those components that contribute to the signature of the MOST system such that the sound pressure level in dBC is reduced by a desired 20 dBC when the system is operated at constant speeds under load. The frequency range of interest was 10 to 8,000 Hz.

A Yamaha ET400TRN Enticer snowmobile and a Norwegian Pulk Sled were used for developing the noise reduction kit, as a typical example of a MOST system.

## **Background**

Most snowmobiles that are currently on the market have air or liquid cooled two-cycle engines. The liquid cooled engines are noticeably quieter than the air cooled because the water absorbs some of the sound. Two-cycle exhaust systems are designed (tuned) for maximum efficiency and power. Most snowmobile manufacturers and exhaust system suppliers have designed their exhaust systems to meet Occupational Safety and Health Administration (OSHA) or Environmental Protection Agency (EPA) specifications. They have not attempted to further reduce snowmobile sound levels because the demand to reduce noise levels any further does not justify the cost to develop the necessary equipment.

Prior to conducting tasks associated with this project we contacted several snowmobile and exhaust system manufacturers. We found out that the main noise causing components were the following, in the order of severity:

- 1.) Engine - Exhaust
- 2.) Track
- 3.) Air Intake

The snowmobile manufacturers purchase exhaust stampings and design their systems through trial and error. The general feeling is that to reduce sound levels produced by the snowmobile a corresponding loss in hp would result. Most exhaust system manufacturers do not design silencers for the two-cycle engines because there is no current need by the general public for quieter vehicles. One manufacturer (Supertrapp) did produce an innovative type of silencer that we wanted to purchase that may have worked on a two-cycle engine but because the design was a series of flat plates, they felt that the oil and particulates in the exhaust would collect on the plates causing a blockage of the exhaust path which could lead to engine problems. Exhaust silencers will be discussed in more detail later in this report.

We realized that most noise from the snowmobile would be of the low frequency type. For example, a common engine idle speed is 2,000 rpm and a maximum engine speed might be 8,000 rpm. At 8,000 rpm the corresponding frequency of combustion (or exhaust) is 133.3 hz. Track noise may even be lower. Low frequency noise is some of the most difficult noise to attenuate. We had a student engineering class perform, as part of their class project, a noise analysis of the Yamaha in non-snow conditions. Although they did not develop any different methods of lowering the noise they did do a one third octave band analysis that showed the highest sound levels at the 250 and 500 hz bands.

### **Test Plan**

After performing some initial research several modifications to the vehicle were planned for the test. In an attempt to reduce engine noise two different sized silencers were purchased, a large diameter and a small diameter silencer. To install these silencers, an exhaust pipe had to be installed onto the end of the tail pipe of the exhaust system on the engine. A photograph of this modification is shown in Figure 1. This was a dissipative or straight through type of silencer with insulation between the passage way and the outside wall of the silencer to absorb the noise. A dissipative silencer is designed for high frequency noise where as a reactive silencer is designed for low frequency noise. An extensive search was made to locate a reactive type silencer for this kit but there were none available that could fit on the Yamaha or were designed for a two-cycle spark ignition engine. The closest type was the Supertrapp but they did not allow us to purchase their model. A reactive silencer is usually large, heavy and designed for stationary power plants. Several articles and books were studied and it may be possible

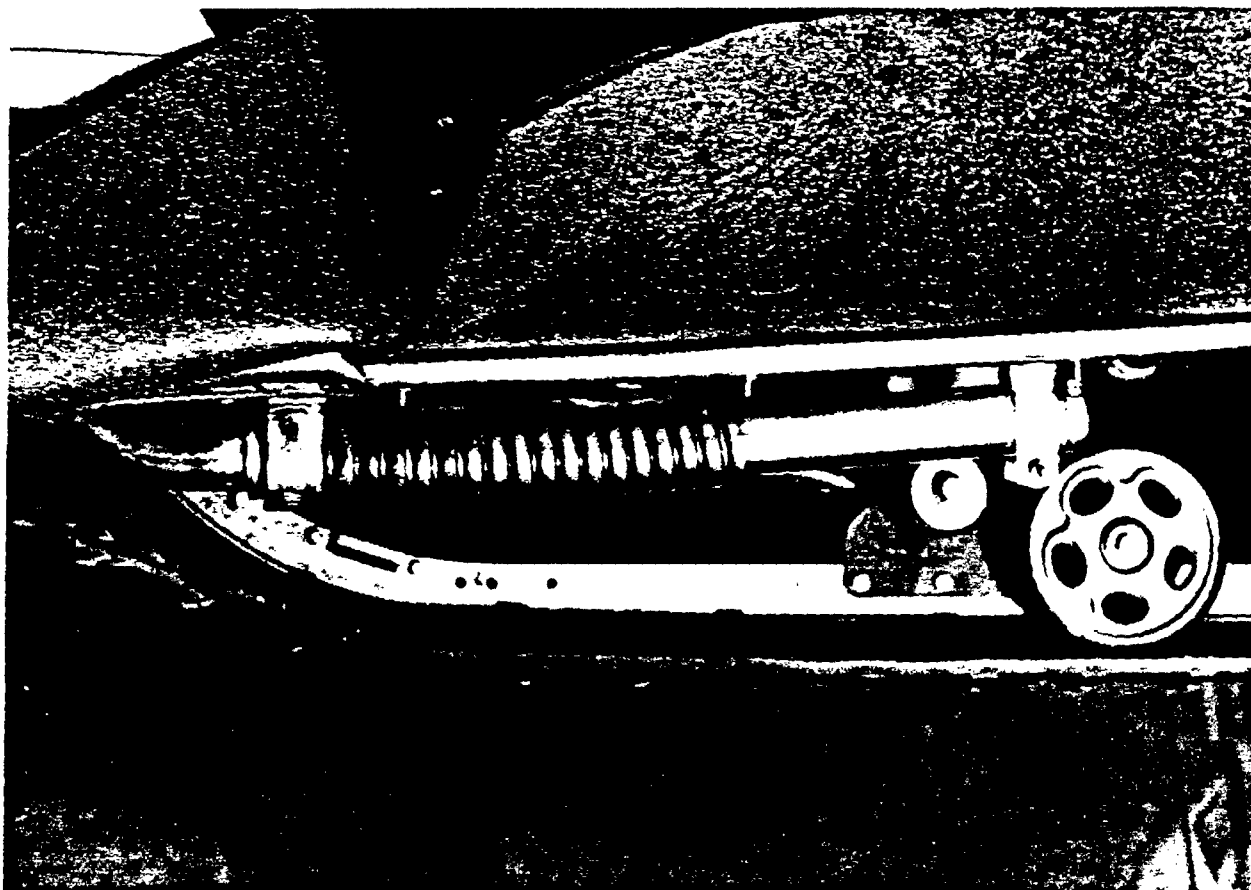


Figure 1. Photograph of exhaust system modification for adaptation of exhaust silencer.

to design a reactive type silencer specifically for this vehicle but it was beyond the scope of this project.

The next modification was to insulate the housing that encloses the engine which includes the belly pan and the cowling. Most of the acoustic material available is designed for higher frequency noise reduction. Also, most cowlings are designed to allow for airflow into the engine compartment and cannot be covered up or the engine may overheat. Since a sizeable portion of the noise is in the low frequency end of the spectrum, a barrier would be better to use than acoustic foam. Acoustic foam absorbs some sound but does not stop the transmission of sound through the walls. A barrier, such as lead, would limit the transmission of sound through the walls but lead would add considerable weight to the vehicle, which also would limit vehicle performance. It was decided to attempt a two-part system in the cowling. Two inch thick SONEX was purchased for the absorbing foam and a vinyl backed foam was purchased for the barrier material. In order to fit these materials into the cowling, the cowling had to be modified as shown in Figure 2. Acoustical foam was not put in the belly pan portion because it would have been a major design change to the snowmobile, whereas, molding a slightly larger cowling would be fairly straight forward. The vinyl backed foam was mounted on all exposed surfaces of the belly pan and cowling aside from those that could possibly cause a fire. Acoustical foam was then cut and fitted over the barrier material on the cowling. Figures 3,4,5 and 6 show photographs of the cowling and belly pan after being modified to accept the acoustic foam/barrier material. All standard production foam was removed from the cowling prior to installation of the noise kit materials. In another modification we used a gray packing foam material instead of the SONEX as it was thicker, but not as dense as the SONEX. A photograph of the Gray Foam Cowling is shown in Figure 7.

The next modification was with the air intake for the engine. The air intake box has a plastic tube routed indirectly through a series of compartments. It is designed to collect particles in these compartments as the air flows through them so they do not get into the engine cylinders and cause damage. All surfaces inside this box are hard and could act as a reverberation chamber. Due to the limited space in these compartments only the vinyl backed foam was placed in as many places as possible in the compartments without reducing airflow. Shown in Figure 8 is the standard air intake box opened to show the airflow pattern and compartments. Figure 9 is a photograph of the modified air intake box with vinyl backed foam.

The final modification was made in an attempt to attenuate noise produced by the vehicle track. To do this we installed a barrier material all around the lower portion of the snowmobile including the rear and front portions near the skis. The barrier had to be designed such that it would not get caught on the terrain it was traversing and tear off of the vehicle. Certain portions were cut to allow movement such as in the rear, directly behind the track, so that when snow is thrown by the track it does not rip the skirt and does not restrict movement. Figures 10 and 11 show the skirt modifications on the Yamaha.



Figure 2. Photograph showing cowling modified to accept sound absorbing material.

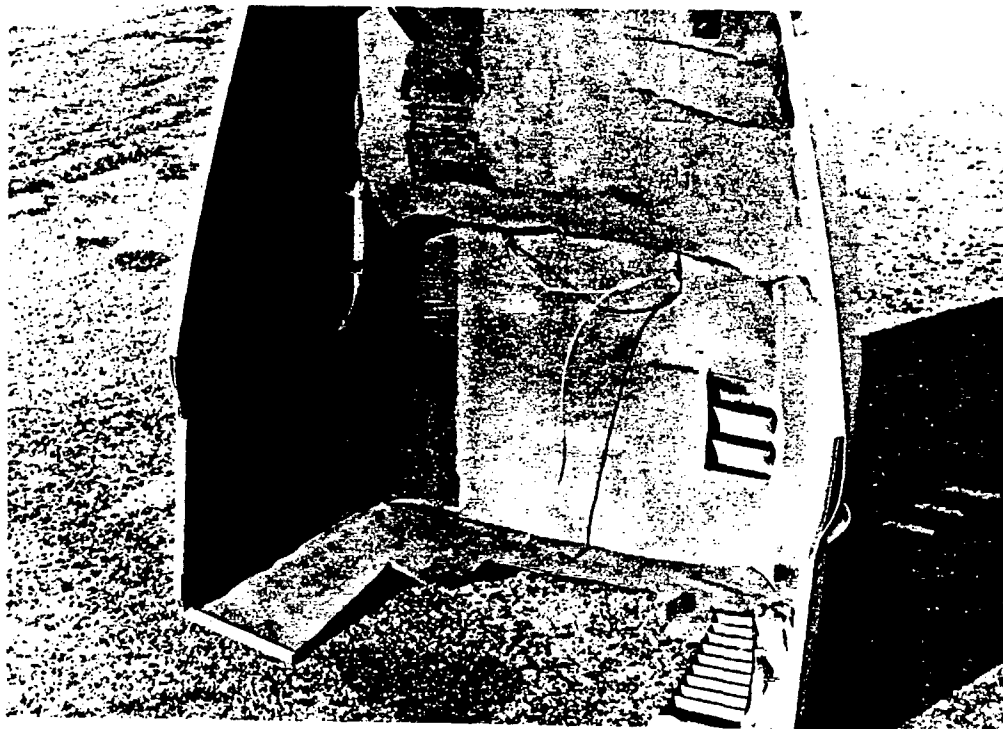


Figure 3. Photograph of cowling with vinyl backed foam installed before installation of thick absorber material.

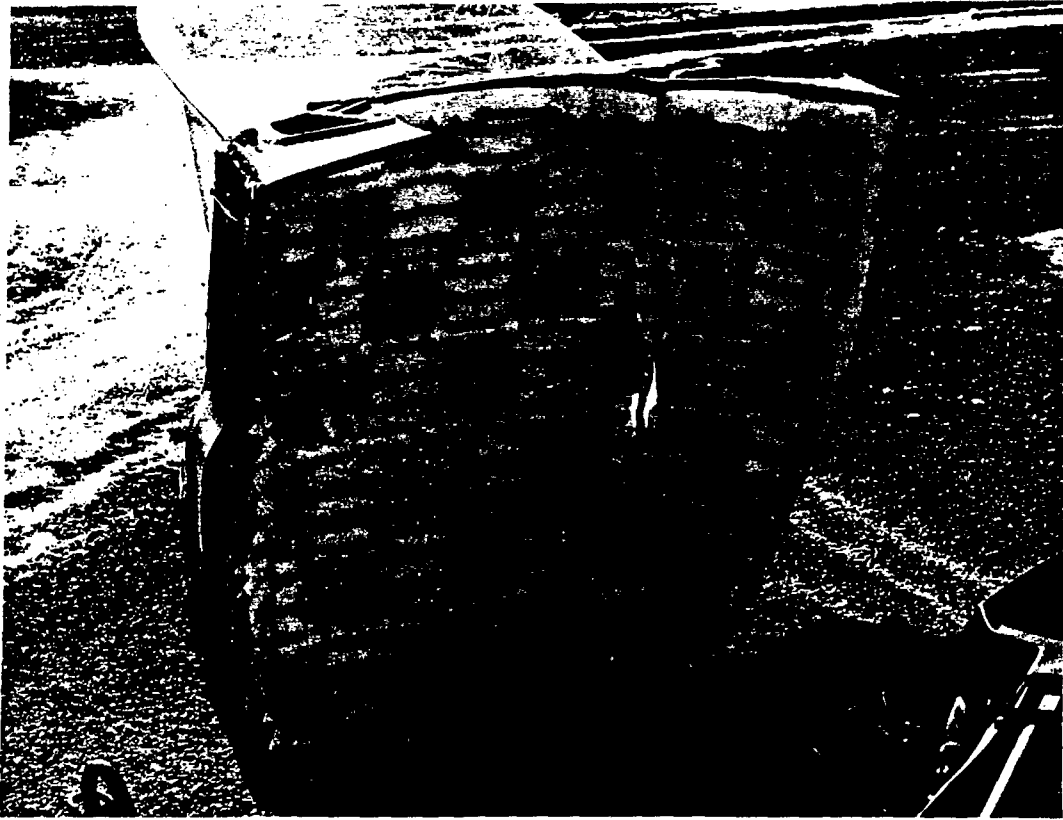


Figure 4. Photograph of cowling with SONEX installed.

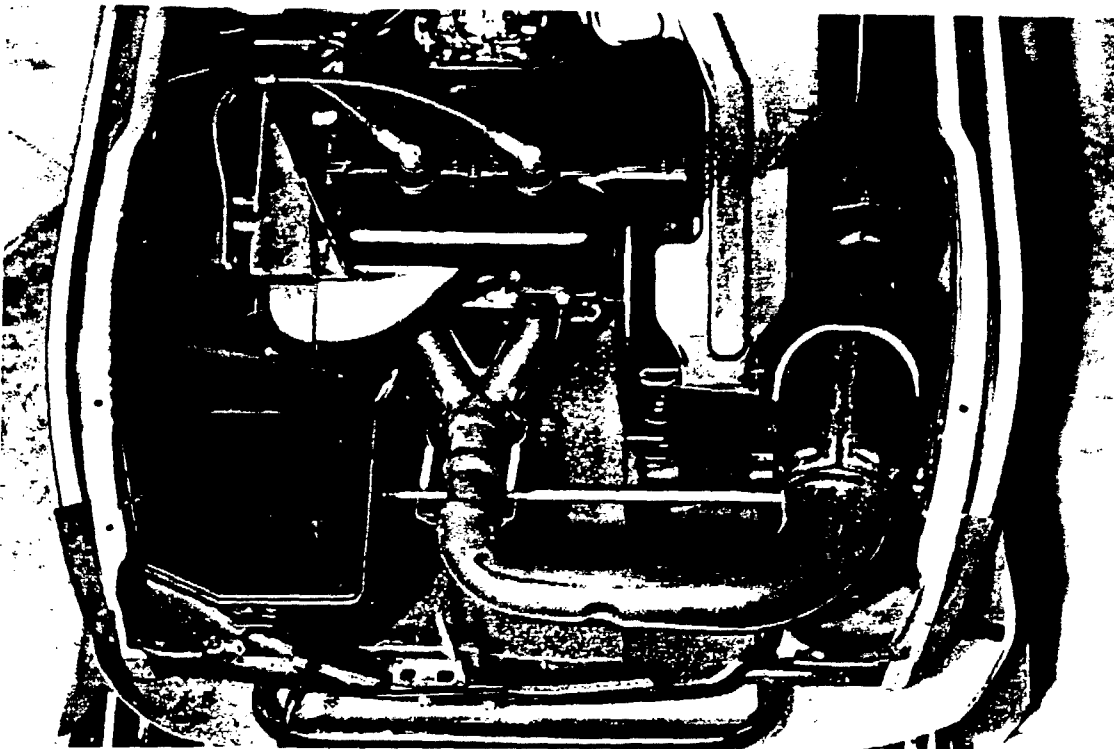


Figure 5. Photograph of belly pan with vinyl backed foam installed.

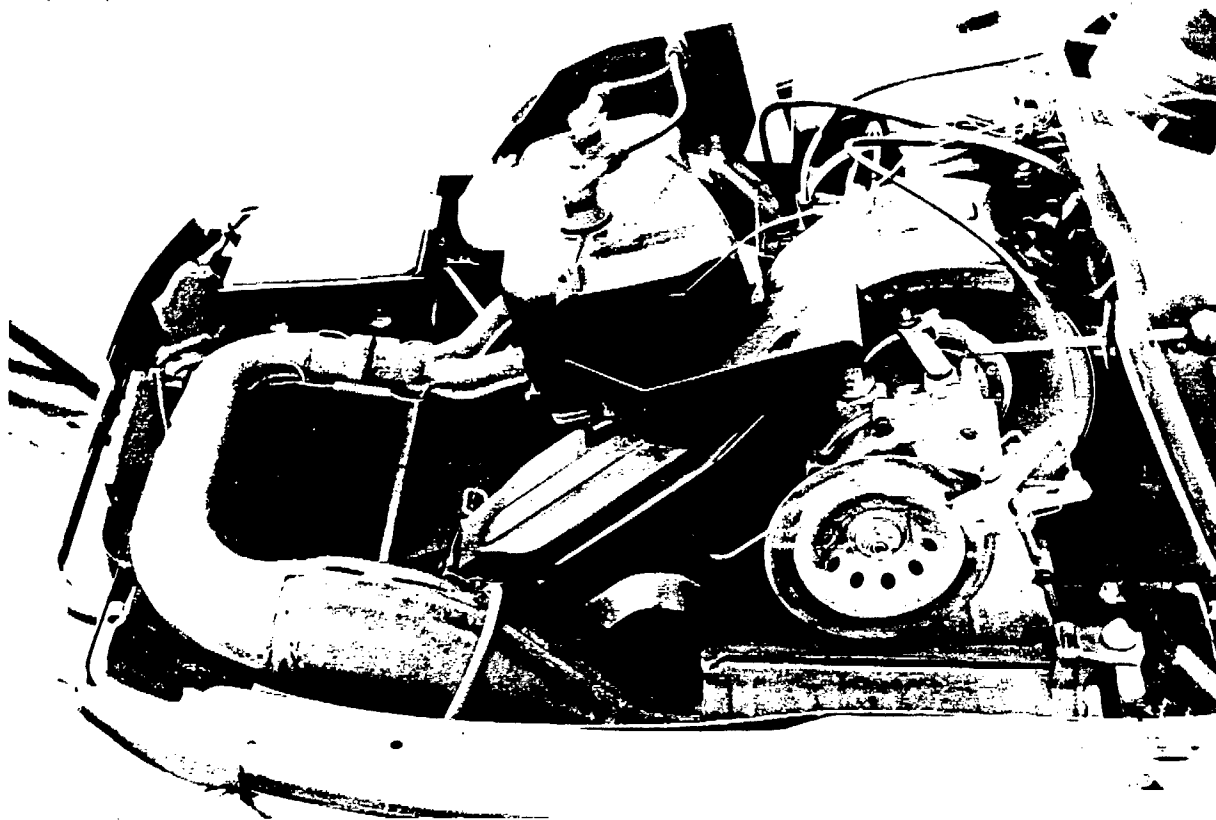


Figure 6. Photograph of belly pan with vinyl backed foam installed.

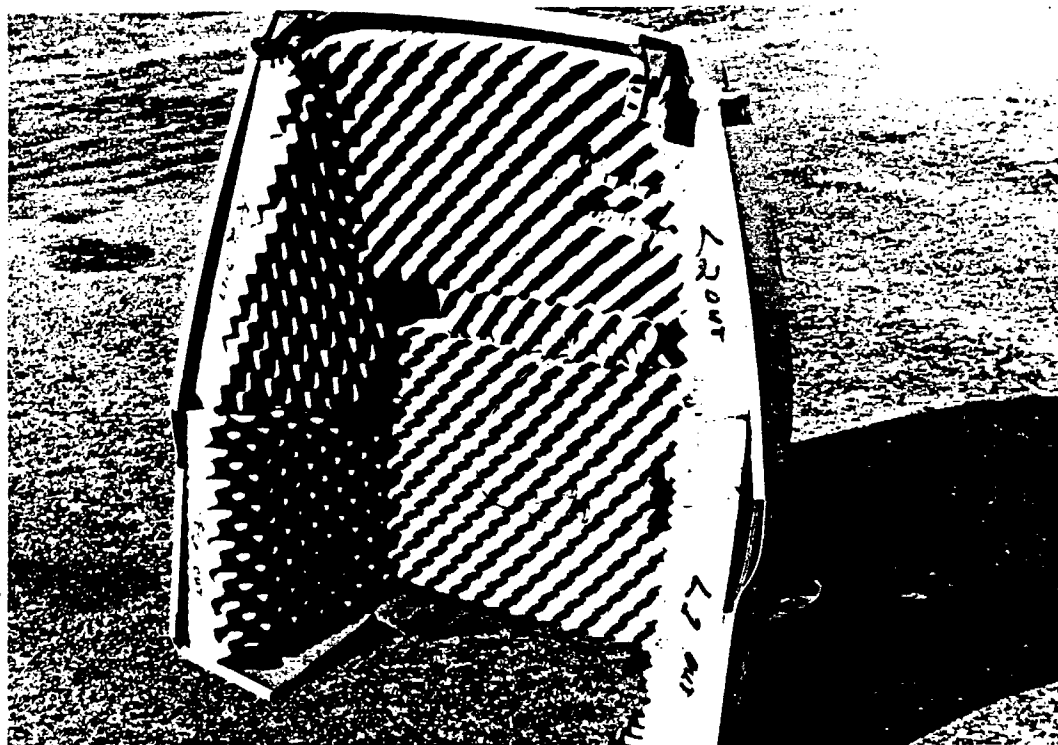


Figure 7. Photograph of cowling with gray foam installed.

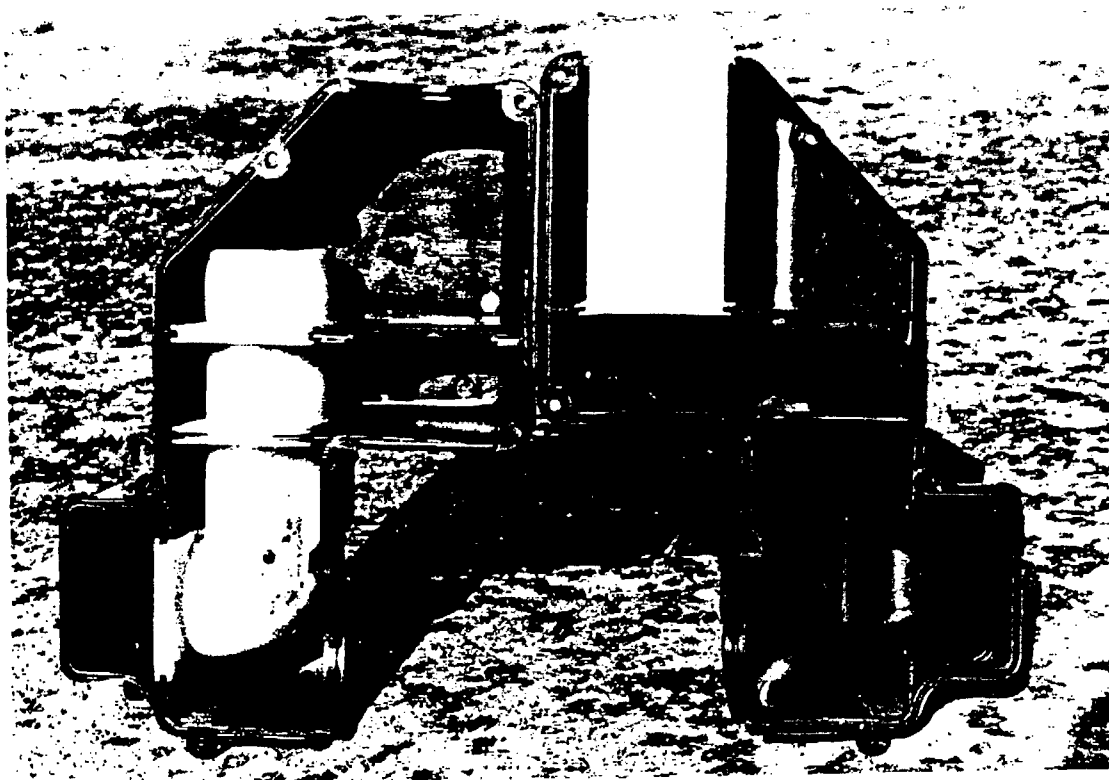


Figure 8. Photograph of standard air intake box.

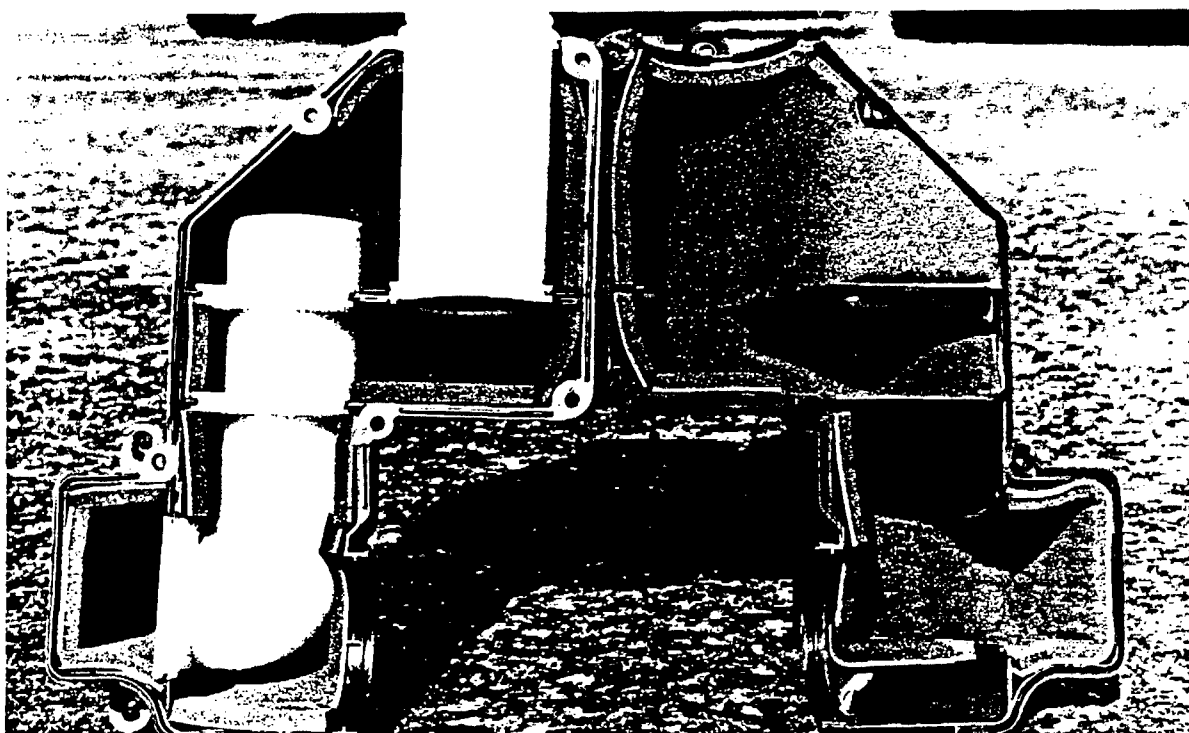


Figure 9. Photograph of air intake box with vinyl backed foam installed.



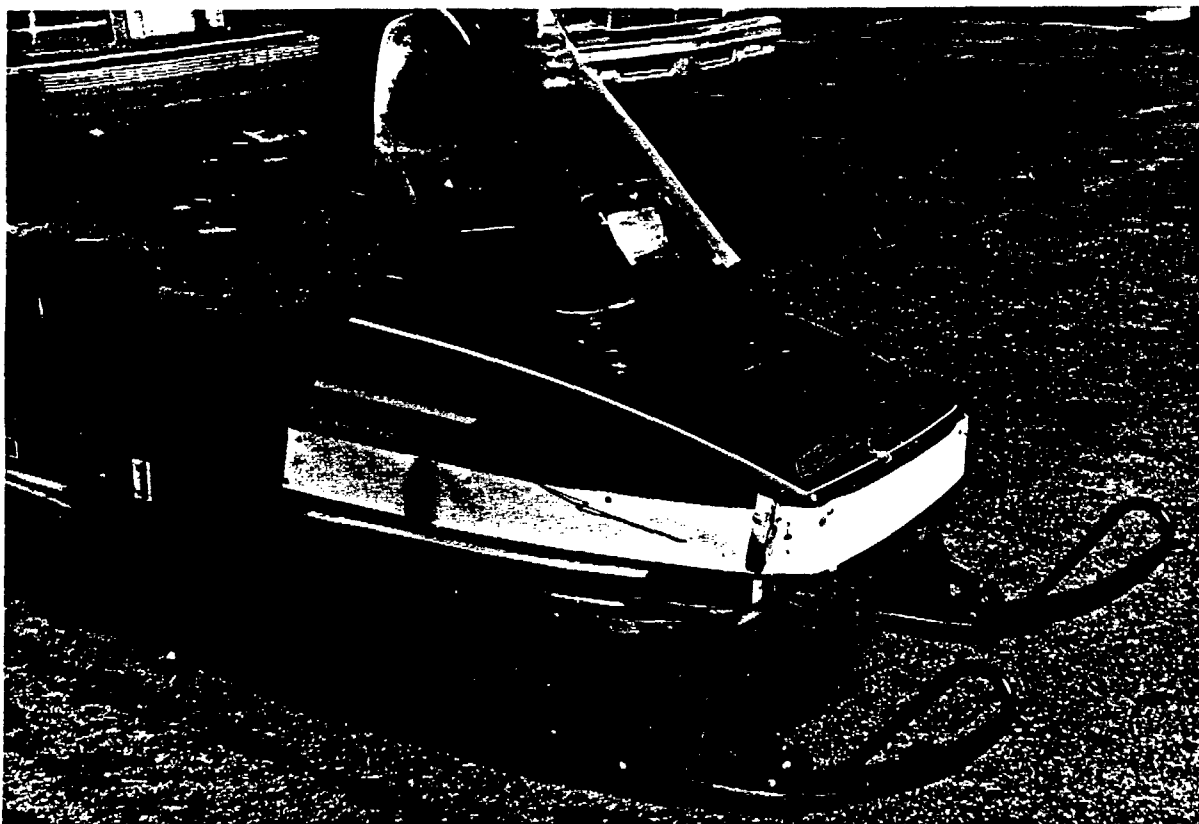


Figure 10. Photograph of Yamaha with skirt installed.

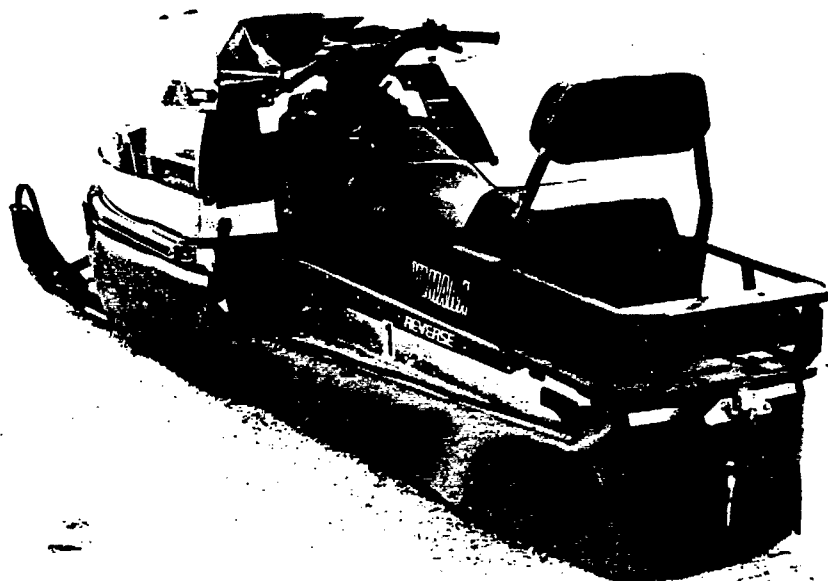


Figure 11. Photograph of Yamaha with skirt installed.

## **Test Procedure**

Procedures outlined in MIL-STD-1474B and TOP 1-2-608 were used for guidance. The test directive for this project was the following, in summary:

- Measure sound levels with vehicle raised off the ground and operated at engine speeds correlating to idle, 10, 20, 30, 40 and 50 mph with microphones in the near field at less than 1 meter and also in the far field at 30 meters for correlation.
- Measure noise level with vehicle at maximum GVW and with a sled at 300 lbs. Microphones are to be located on either side of the system at 30 meters to record sound while the system is moving at constant speeds of 10, 20, 30, 40 and 50 mph.
- Obtain the impedance value of snow densities in the range from 0.15 to 0.40 gms/cc for input into the ADRPM.
- Sound level measurements are to be made in both dBA and dBC in the 10 to 8,000 Hz frequency range.
- MIL-STD-1474B suggests that a windscreen be used for any measurements recorded when the wind speed is greater than 6 mph and that measurements not be taken when the wind speed is greater than 12 mph.
- Monitor climatic conditions such as ambient air temperature, relative humidity, wind speed and direction as well as snow depth, density, temperature and classification.
- Monitor and record engine speed and vehicle speed.

Since the major thrust of this project was to develop a kit to reduce the acoustic signature of the MOST vehicle, we varied our procedure slightly. The following describes our methods:

- We recorded all sound level measurements in the linear frequency range such that it could be played back through our tape recorder in any frequency weighting desired. This reduced the number of tests to conduct as well as variables between test runs.

- The student group made measurements with the vehicle off of the ground but our measurements were at idle and passby readings at 10, 20 and 30 mph. For both the idle and passby recordings, microphones were located at both 1 meter and 30 meters from the vehicle/sled combination. Idle readings were made at four locations around the vehicle, 90° apart, for each modification. Passby readings were made by having the driver move by the microphones in each direction such that measurements were recorded from both the left and right sides of the vehicle system.
- There was no tachometer available on this particular vehicle and there was no convenient way of setting a tachometer up for measuring engine speed. Many snowmobiles have tachometers available on them but this one did not. Also, the top speed of the snowmobile in the reasonable length of approach area available was only 30 mph.
- We did not perform the tests with the vehicle off of the ground at speeds of 10, 20, 30, etc. because we felt track slip during most driving conditions led to results not comparable to these static measurements.

Initial measurements were made both by KRC and the student group. The final three days of measurements were the most critical and will be the subject of discussion in this report. Figures 12, 13 and 14 show the layout of the microphones and sound level meters for each of the three days of testing. These sketches show wind speed and direction relative to the vehicle and microphone locations on these three days of testing.

### **Test Equipment**

The following list of instrumentation was used for noise data acquisition and analysis for all of the test data in this report.

#### **Near Sound Level Meter**

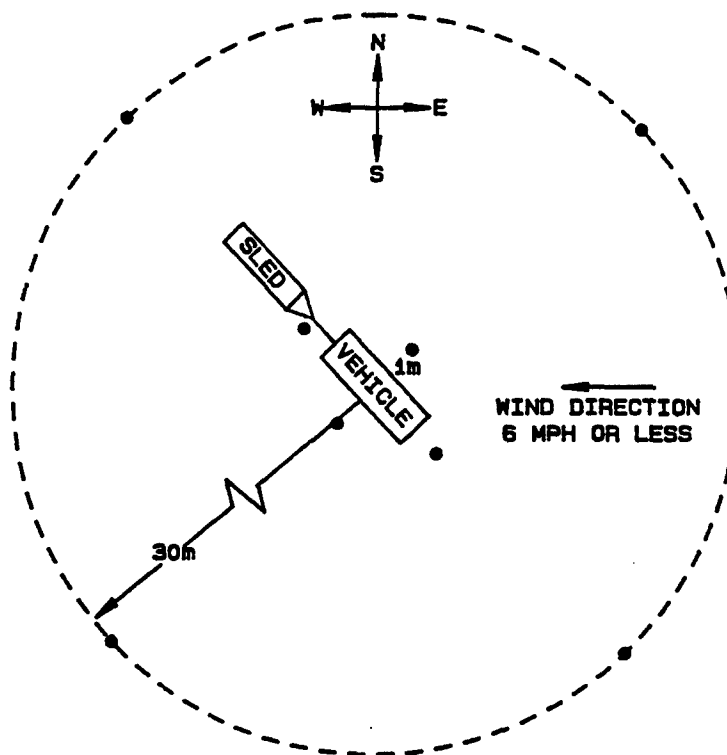
Meter - B&K Type 2230, S/N 1428627

Microphone - B&K Type 4155, S/N 1479278, Prepolarized Condenser Type, Calibrated 3/16/89

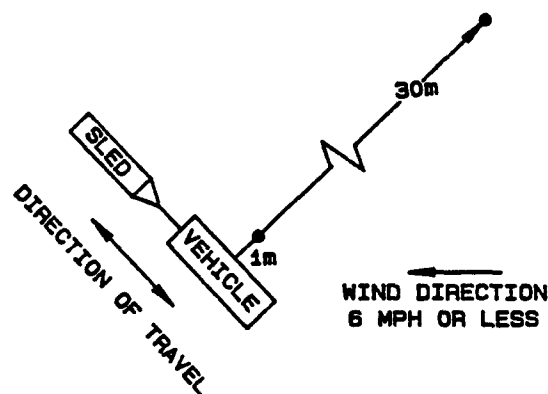
#### **Far Sound Level Meter**

Meter - B&K Type 2203, S/N 555456

Microphone - B&K Type 4133, S/N 998480, Condenser Type, Calibrate 6/15/82

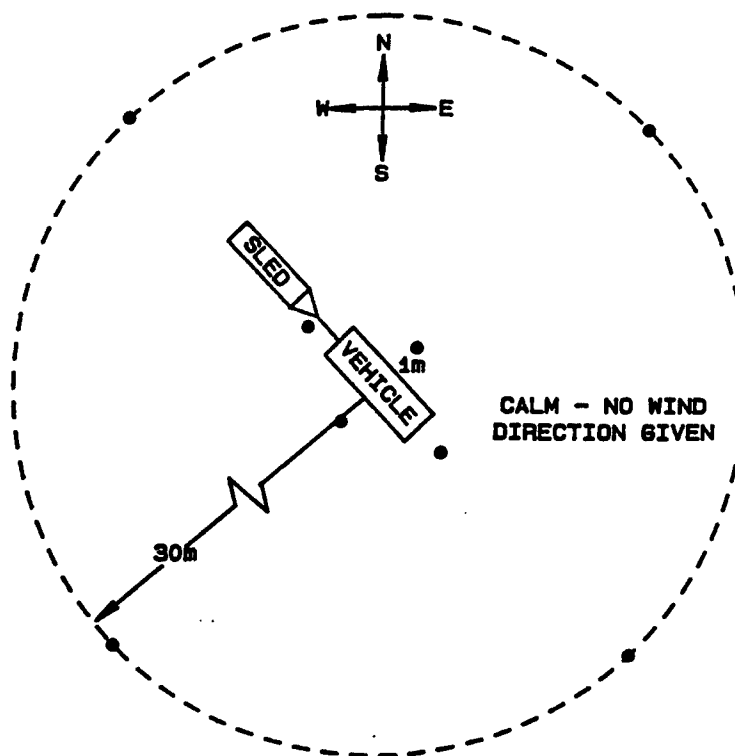


LOCATION OF MICROPHONES (●) AND POSITION OF VEHICLE DURING  
IDLE TESTS MARCH 14, 1991 WITH REFERENCE TO WIND DIRECTION

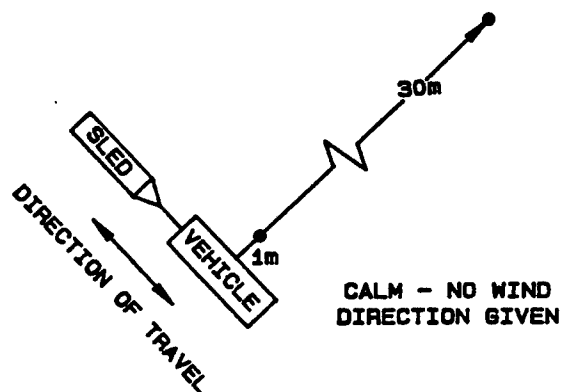


LOCATION OF MICROPHONES (●) AND DIRECTION OF TRAVEL DURING  
PASSBY TESTS MARCH 14, 1991 WITH REFERENCE TO WIND DIRECTION

Figure 12. Sound measurement test layout for testing on March 14, 1991.

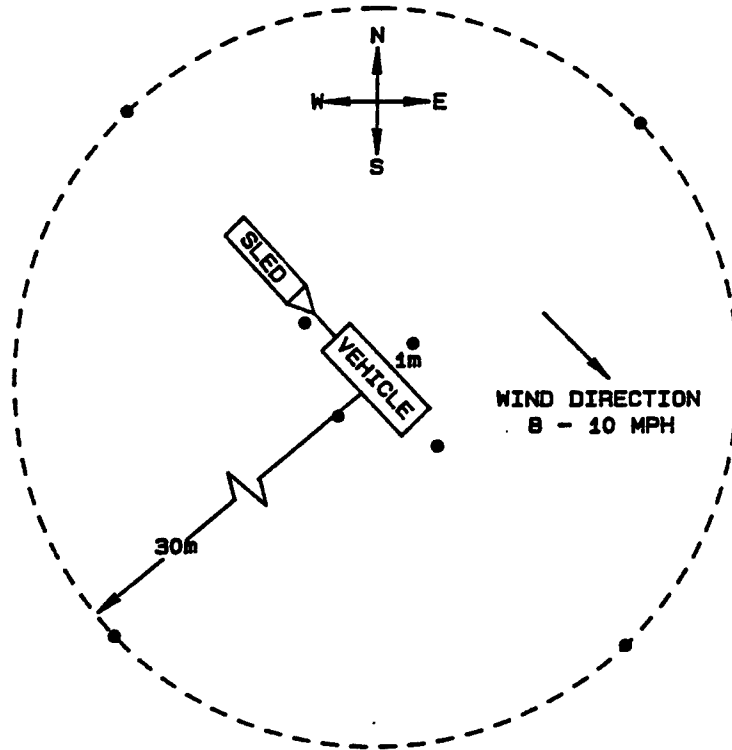


LOCATION OF MICROPHONES (●) AND POSITION OF VEHICLE DURING  
IDLE TESTS MARCH 15, 1991 WITH REFERENCE TO WIND DIRECTION

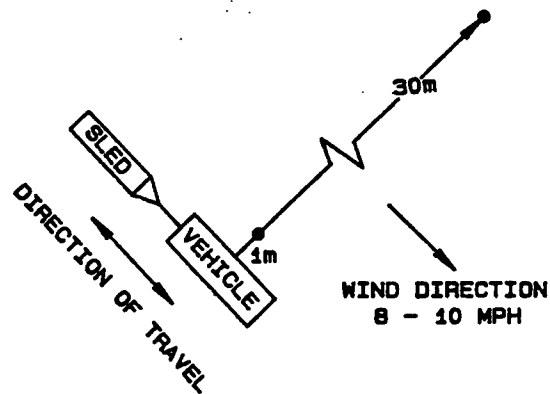


LOCATION OF MICROPHONES (●) AND DIRECTION OF TRAVEL DURING  
PASSBY TESTS MARCH 15, 1991 WITH REFERENCE TO WIND DIRECTION

Figure 13. Sound measurement test layout for testing on March 15, 1991.



LOCATION OF MICROPHONES (●) AND POSITION OF VEHICLE DURING  
IDLE TESTS MARCH 18, 1991 WITH REFERENCE TO WIND DIRECTION



LOCATION OF MICROPHONES (●) AND DIRECTION OF TRAVEL DURING  
PASSBY TESTS MARCH 18, 1991 WITH REFERENCE TO WIND DIRECTION

Figure 14. Sound measurement test layout for testing on March 18, 1991.

**Sound Level Meter Calibrator**

B&K Type 4230 94dB - 1,000 Hz  
(93.8 dB for 1/2 inch microphones)

**Tape Recorder**

TEAC PCM Data Recorder, Model RD-101T, S/N 712346

**Data Analysis Equipment**

B&K Type 3347 Real-time 1/3 Octave Band Analyzer  
B&K Type 2130 Frequency Analyzer (S/N 355371)  
B&K Type 4710 Control and Display Unit (S/N 357401)

**Compaq Computer, S/N 296045**

W/Data Translation A/D Board Model DT5712, S/N 115333-446

**Dynamic Signal Analyzer**

Hewlett-Packard Model 3562A, S/N 2502A01540

All data was measured and recorded using the above mentioned sound level meters and TEAC tape recorder. For data analysis the tape was played back through the sound level meter in the C-scale and either onto the Compaq for time series plots or into the octave band analyzer or frequency analyzer for different types of analysis. Most readings were made at the fast response time and analyzed in the slow time response as directed by MIL-STD-1474B.

On each of the final three days of testing several kit modifications were tested. Each day the sound level meters were calibrated at the beginning, middle and end of the day. Ambient measurements were recorded at the beginning of the day and at the end of testing on that particular day. Each day a windscreen was used on the microphones and testing was not conducted on days when the wind speed was greater than 12 mph. On some days wind speed was recorded as calm. The wind speed readings were recorded by the local airport FAA weather station which was within a half-mile of the test site. Calm wind speeds were 5 mph or less. A stock machine test was done on each day of testing for reference purposes in case other variables such as snow characteristics changed from one day to the next.

**Discussion of Test Results**

The tests early on in this project and those done by the student group basically told us that the problem frequencies were at very low frequencies, i.e., 500 Hz or less. With this

information in mind, modification kits were designed to either absorb the sound or reduce transmission of the sound.

The first day the following tests were run:

- 1.) Stock configuration
- 2.) Bare Cowling
- 3.) Sonex Cowling
- 4.) Modified Air Intake
- 5.) Insulated Pan
- 6.) Full Package

The stock configuration was taken as a reference. The bare cowling was with the stock foam insulation removed but the results are not discussed since they were not critical to this project. The Sonex cowling used the Sonex with the vinyl backed foam. The modified air intake used the vinyl backed foam. The insulated pan used only vinyl backed foam as the Sonex could not fit in most places. The full package utilized the insulated pan, modified air intake, Sonex cowling, the small silencer and the skirt. Information on sound transmission loss and absorption coefficients for the vinyl backed foam and the SONEX are presented in Appendix A.

On the second day of testing the following tests were run:

- 1.) Skirt
- 2.) Gray foam cowling
- 3.) Stock configuration

The skirt utilized only vinyl backed foam. The gray foam cowling was a non-acoustically rated foam. It was used because it was lighter, more porous and thicker than the Sonex purchased for this project. It was also used with the vinyl backed foam as a barrier. The stock configuration was again tested for reference.

On the third day of testing the following tests were run:

- 1.) Stock configuration
- 2.) Large silencer
- 3.) Small silencer

The stock configuration was again tested for reference. The large silencer was two inches in diameter. The small silencer was 1.5 inches in diameter. Both silencers were purchased from a common vehicle parts discount mail order company (J.C. Whitney) and required some modification to the exhaust system.

Again, all test modifications were run with the vehicle at idle and passby at 10, 20 and 30



mph with a sled with 300 lbs of cargo. Idle measurements were taken at four positions around the vehicle system, on the left (exhaust side), in front, on the right and at the rear, both at 1 meter and 30 meters from the vehicle. Passby measurements were made on the left and right sides of the vehicle at 1 meter and 30 meters from the vehicle.

### **Types of Analysis**

Three types of analysis were used to analyze the data and evaluate the results. First, a very general broad overview was made for all modification kits which was done by comparing average peak sound level values in dBC. These data are shown in Table 1. From this information we could see that the modified air intake did not seem to reduce levels significantly. Also, the small silencer appeared to reduce levels more than the large silencer. The Sonex cowling reduced levels more than the gray foam cowling. In this analysis the skirt did not appear to reduce sound levels significantly. When the skirt was tested there was a notable reduction in sound to the human ear which meant that sound was reduced by 1 dB at a minimum and probably 3 dB. The full package did reduce sound levels fairly well at idle but not significantly at the higher speeds. There were some occurrences that did not seem realistic, such as the sound level on the right side being higher than on the left side.

Next we performed an octave band analysis on the data to determine what the problem frequencies were for each test. We felt that this might also help us determine what noise was caused by wind or the sled. Most of the noise was at 5 kHz or below and the highest concentrations were at 500 Hz or less. This was done for a select few tests that we felt most concerned with. The octave band analysis did not help us to a great extent other than determining the frequency content of the noise. It should be noted however that these octave band plots show in a comparison of stock vs. full package, that a large amount of noise in the 500 to 5,000 Hz range was attenuated by the full package at the higher vehicle speeds. The overall average sound level was virtually unchanged or in some cases slightly higher than the stock package. Typical octave band analysis plots are shown in Appendix B.

The final type of analysis was a spectral analysis. This was done for a stock configuration, an ambient taken right after the stock test, the skirt test, an ambient taken right before the skirt test and a full package test. We analyzed the ambient data and the modifications then we subtracted ambient (background) noise from each test such that wind effects were removed. The results basically showed a significant reduction in sound levels using the skirt and using the full package as tested. In the case of the skirt test, it was noted that wind speeds were high at the beginning of the day during both the initial ambient test and the skirt test. The stock configuration was tested at the end of the day when ambient levels were significantly lower and the winds had died down. By removing the appropriate ambients in each case a significant reduction in sound levels were seen. Peak values from the adjusted spectral analysis plots are shown in Table 2.

Table 1 Maximum Sound Levels During Pass-By And Average Idle Levels In dBC From March 14, 1991

	Stock	Sonex Cowl	MA Intake	Ins. Pan	Full Pkg.	
10 mph, Left Side Near	85.8	86.4	87.3	87.1	88.2	Note: Wind Blowing From Meters Toward Machine At Angle.
Left Side, Far	86.5	84.3	86.6	88.2	86.9	
Right Side, Near	87.4	82.7	87.0	86.4	83.7	
Right Side, Far	86.3	82.6	87.0	87.0	86.9	
20 mph, Left Side, Near	90.9	90.7	93.0	93.0	92.0	
Left Side, Far	83.8	61.9	64.0	63.0	64.5	
Right Side, Near	89.8	87.4	89.7	90.8	90.9	
Right Side, Far	62.0	88.4	61.7	62.6	62.0	
30 mph, Left Side, Near	92.5	91.9	93.2	91.5	91.5	
Left Side, Far	66.2	64.3	66.3	65.1	64.8	
Right Side, Near	90.2	91.3	92.7	94.0	90.8	
Right Side, Far	64.2	63.9	64.8	66.6	61.8	
Idle, Left Side, Near	83.9	84.0	84.7	84.4	78.7	
Left Side, Far	49.7	52.3	52.7	52.1	48.8	
Front Side, Near	83.2	78.7	91.5	81.8	73.4	
Front Side, Far	50.2	49.3	50.8	50.6	46.1	
Right Side, Near	84.7	80.0	83.4	82.3	77.1	
Right Side, Far	52.1	54.6	53.9	53.8	50.4	
Rear, Near	80.2	48.8	77.8	79.2	77.5	
Rear, Far	51.1	44.4	50.8	51.7	50.0	

**Table 1 Cont'd. Maximum Sound Levels During Pass-By  
And Average Idle Levels in dBC From March 15, 1991**

	Stock	Skirt	Gray Foam Cowling
10 mph, Left Side, Near	87.0	86.1	85.2
Left Side, Far	88.1	89.1	86.4
Right Side, Near	86.6	87.2	84.3
Right Side, Far	87.9	88.5	85.3
20 mph, Left Side, Near	92.1	91.8	90.9
Left Side, Far	94.3	95.5	91.7
Right Side, Near	89.7	90.4	87.0
Right Side, Far	92.8	94.2	90.0
30 mph, Left Side, Near	91.0	90.5	91.4
Left Side, Far	96.5	97.2	95.5
Right Side, Near	91.0	91.1	90.8
Right Side, Far	96.1	96.5	94.2
Idle, Left Side, Near	85.1	84.1	83.7
Left Side, Far	84.5	85.9	83.3
Front, Near	83.4	82.4	80.3
Front, Far	82.8	84.3	80.5
Right Side, Near	84.5	85.8	81.6
Right Side, Far	84.7	88.9	83.4
Rear, Near	80.2	81.0	81.1
Rear, Far	83.0	83.6	81.4

**Table 1 Cont'd.      Maximum Sound Levels During Pass-By  
And Average Idle Levels in dBC From March 18, 1991**

	Stock	Large Silencer	Small Silencer
10 mph, Left Side, Near	87.3	84.1	85.3
Left Side, Far	60.6	60.5	61.2
10 mph, Right Side, Near	86.8	85.4	85.0
Right Side, Far	59.8	62.7	68.4
20 mph, Left Side, Near	91.4	85.8	84.4
Left Side, Far	68.8	62.9	65.4
20 mph, Right Side, Near	86.8	86.4	89.8
Right Side, Far	64.3	62.4	67.5
30 mph, Left Side, Near	90.8	92.5	88.1
Left Side, Far	67.9	67.5	66.6
Right Side, Near	90.0	88.6	79.8
Right Side, Far	67.2	66.3	55.1
Idle, Left Side, Near	82.2	81.3	78.2
Left Side, Far	53.1	60.3	57.7
Front, Near	81.5	78.4	81.3
Front, Far	53.0	59.4	61.5
Right Side, Near	84.4	81.3	76.2
Right Side, Far	56.8	58.8	56.9
Rear, Near	79.7	76.6	60.5
Rear, Far	52.6	56.6	60.5

**Table 2 Peak Noise Levels (dB) From Spectral Analysis With Ambient Removed**

<b>Location</b>	<b>Stock</b>	<b>Skirt</b>	<b>Full Package</b>
<b>Idle, Left Side</b>	<b>59.2</b>	<b>49.0</b>	<b>41.4</b>
<b>Idle, Front</b>	<b>56.0</b>	<b>44.1</b>	<b>36.7</b>
<b>Idle, Right Side</b>	<b>57.1</b>	<b>45.4</b>	<b>41.5</b>
<b>Idle, Rear</b>	<b>52.7</b>	<b>44.3</b>	<b>14.6</b>
<b>10 mph, Left Side</b>	<b>62.6</b>	<b>51.2</b>	<b>26.8</b>
<b>10 mph, Right Side</b>	<b>71.4</b>	<b>56.2</b>	<b>25.6</b>
<b>20 mph, Left Side</b>	<b>76.2</b>	<b>59.2</b>	<b>39.3</b>
<b>20 mph, Right Side</b>	<b>71.4</b>	<b>61.9</b>	<b>37.7</b>
<b>30 mph, Left Side</b>	<b>79.0</b>	<b>65.4</b>	<b>37.7</b>
<b>30 mph, Right Side</b>	<b>79.0</b>	<b>66.0</b>	<b>37.5</b>

The winter season ended sooner than normal this year and therefore the testing was limited. If there was time we would have liked to run a couple more tests to make some final evaluations. It would have been best to run a final full package without the modified air intake to prove that this did not significantly reduce sound levels. It would also be good to run tests, at least with the stock and full package both with and without the sled. In our analysis it appears that the sled contributes a significant amount of random low frequency noise when moving at the high speeds over bumps. On a hard-packed surface this could be significant but in deep powder snow it will not be a problem.

Weather information for the three days of testing is shown in Table 3. Information was collected through the FAA weather station which was approximately one half mile from the test site. Readings were usually taken three times per day. Snow characteristics were measured but did not change much. The snow was very hard-packed, and old with approximately 1-3 inches of soft snow on the top layer. The soft snow was a result of the warm ambient temperatures and solar radiance. Since the snow we were concerned about was the top layer only, its density is reported and was 0.32 g/cc. The layer below this was almost too hard to make a snow density measurement. Snow temperature was  $-0.6^{\circ}\text{C}$  at the surface and  $-5.6^{\circ}\text{C}$  at six inches below the surface.

**Table 3 Weather Data For Final Three Days Of Testing**

<b>Date</b>	<b>Time</b>	<b>Temp. (°F)</b>	<b>Rel. Humidity (%)</b>	<b>Wind (Speed/Dir.)</b>
<b>3-14-91</b>	<b>11:00</b>	<b>29</b>	<b>60</b>	<b>6/E</b>
<b>Sunny</b>	<b>12:00</b>	<b>33</b>	<b>50</b>	<b>Calm</b>
	<b>2:00</b>	<b>34</b>	<b>55</b>	<b>Calm</b>
<b>3-15-91</b>	<b>1:00</b>	<b>38</b>	<b>55</b>	<b>Calm</b>
<b>Sunny</b>	<b>2:00</b>	<b>39</b>	<b>45</b>	<b>Calm</b>
	<b>3:00</b>	<b>40</b>	<b>45</b>	<b>Calm</b>
<b>3-16-91</b>	<b>8:00</b>	<b>33</b>	<b>89</b>	<b>10/W</b>
<b>Cloudy</b>	<b>10:00</b>	<b>33</b>	<b>96</b>	<b>8/WNW</b>
	<b>12:00</b>	<b>34</b>	<b>92</b>	<b>11/W</b>

## **Conclusions and Recommendations**

Before discussing the conclusions it is important to point out to the reader that a 3 dB reduction in sound level is a 50 percent reduction in acoustic intensity. To reduce the sound level 20 dB the acoustic intensity would have to be reduced significantly and this would probably produce a significant adverse effect on the performance of the vehicle. Another point to be made is that a  $\pm 0.5$  dB error is typically associated with sound level measurements and analysis. The actual error depends a great deal on the quality of the microphone and the sound level meter as well as how well the tests are carried out by the personnel. We used fairly high quality microphones, sound level meters and tape recorders. The author would expect the error for these tests to be near the standard  $\pm 0.5$  dB range.

From this study several conclusions can be made relative to the noise produced by a snowmobile.

- 1.) The most significant contributions are from the engine and the track. Because of the mechanisms involved, most of the noise is at low frequencies 500 Hz or less.
- 2.) The air intake may contribute to the noise produced by the snowmobile but this is difficult to isolate due to the fact that engine noise is greater and the engine has to be running in order to create the air intake noise.
- 3.) Other contributors to noise may be the centrifugal drive clutch and chain drive system.
- 4.) It should be pointed out that although the full package results at 20 and 30 mph do not show an overall decrease as compared to the stock package, the results do show a decrease in the octave bands of 500 to 5,000 hz. It may possibly be that the low frequency sled noise becomes more prevelant when the higher frequency noise is attenuated. By observation, we noted that by the end of the day, the course had become quite bumpy and sled noise had audibly increased. Also, as explained in the following recommendations, a thicker absorbent material is necessary for adequate attenuation of the frequencies below 500 hz. More testing is required to determine how much the sled contributes to the overall noise level.
- 5.) Wind noise can either attenuate or enhance the sound from a snowmobile depending on the direction and magnitude of the wind.
- 6.) Snow may absorb some engine noise and reduce track noise if its density is low enough. This has not been quantified in this study.



- 7.) The full package noise kit reduced sound levels by 3 to 10 dBC at idle but did not significantly reduce sound levels at the greater vehicle speeds.
- 8.) By performing a spectral analysis of the stock, full package and ambient readings and subtracting the wind noise from the stock and full package readings, all results were significant. Results showed decreases up to 40 dBC or more by using the full package, although we are not fully confident of this analysis because the reductions realistically seem too large.

From this study several recommendations may be made as to an add-on kit and also to the stock snowmobile which may be used as part of the MOST program.

- 1.) It is recommended that a snowmobile with a liquid cooled engine be used. Liquid cooled engines are noticeably quieter than air cooled engines as the liquid absorbs some of the internal engine sounds. It is thought that the thermal signature would also be less as the liquid keeps the engine cooler.
- 2.) Many of the snowmobiles produced in the last two years (1989 and 1990) have air intake boxes designed with thick, porous foam. This reduces snow ingestion as well as air intake noise. It is recommended that the MOST vehicle have an air intake designed with foam.
- 3.) As part of the noise reduction kit it is recommended that the MOST vehicle have a special cowling designed for quiet operation. In order to reduce the noise signature a barrier and absorber material will have to be added to the cowling. To accomodate the addition of this material the cowling will have to be similar to that shown in Figure 2. The design of the cowling will be dependent upon the snowmobile that is finally purchased. It is recommended that a barrier material be attached to the inside surface of the cowling. This does not have to be a very thick material but should have comparable barrier characteristics as good or better than the vinyl backed foam used in this project. It is also recommended that a thick absorbing type foam that is flame resistant be installed on top of the barrier material. This should be a minimum of two inches thick and three to four inches would be even better. Care must be taken to not block any of the air vents on the cowling because the engine may become overheated if air is restricted.
- 4.) The pan area or bottom part of the front portion should have at least a barrier material comparable to the vinyl backed foam. It may be possible to obtain more noise reduction by putting some absorbing material in the pan but on most snowmobiles produced in the last few years, there is not enough room for a thick absorber material without problems with interference of engine or drive mechanisms.

- 5.) It is recommended that a barrier type material be used in the design of a skirt around the lower portion of the snowmobile to eliminate track noise. This skirting is believed to help reduce noise produced by the exhaust by acting as a barrier and deflecting much of the exhaust noise into the snow and allowing the snow to absorb some of this noise.
- 6.) If the military requires a significant reduction in sound it is recommended that a follow-on study be conducted to further refine the noise kit. In retrospect, it is felt that a more effective kit could be developed provided that suitable funding is available. In order to develop an effective kit it would be best to have the actual vehicle that will be purchased for the MOST. Although most snowmobiles have similar characteristics, the designs developed in the proposed study would be specifically tuned to the particular vehicle of interest. The study would consist of the following areas:
- A.) First, it is recommended that three areas be studied: the effect of track noise, attempt to isolate engine noise and noise related to engine speed. The student group attempted to measure track noise but it is felt that this should be done again. Track noise can be measured by having the vehicle transmission in neutral and running the engine at speeds comparable to a moving vehicle at speeds of 10, 20, 30 and 40 mph.
- Engine noise can be studied by running a long exhaust hose away from the vehicle and making noise measurements close to the vehicle. During this test it is suggested to monitor engine speeds with a tachometer and also record vibrations by instrumenting the engine with accelerometers. By running the engine at speeds comparable to vehicle speeds of 10, 20, 30 and 40 mph under these conditions, engine noise can be related to speed and vibrations. A spectral analysis of both engine noise and vibration will indicate the problem frequencies of the engine which will allow us to better match materials for reducing engine noise.
- B.) Three basic areas on the vehicle will be concentrated on for improving noise attenuation. These are, the engine compartment (cowling and pan areas), the exhaust system and the skirt (track).
- B.1) It should be realized that unless all holes in the cowling could be eliminated thereby sealing off the engine, the noise emitted from the engine compartment can never be totally eliminated no matter how good a barrier or how thick an absorber is used. The best that could be hoped for is a significant

reduction, possibly to near ambient levels. The cowling and pan will act as both a barrier and an absorber but with air flow holes in the cowling the barrier is not complete and therefore some sound will be emitted. With a reasonable amount of absorption, hopefully, a sizeable amount of the noise can be absorbed before it is emitted from the cowling. In order to accomodate a thick foam absorber a special cowling would be designed and fabricated. Once the engine frequencies are isolated a good absorber, such as SONEX I approximately four inches thick, would be installed on the cowling and parts of the pan area in between the engine and the barrier.

For optimal acoustic absorption the thickness of the material divided by the wavelength of the sound should be greater than 0.10. Now that it is known that the problem frequencies are 500 Hz or less it is known that the absorber thickness should be 2.6 inches or thicker. One should also realize that eight inches of foam would result in a significant reduction of noise but there are practical limits to the size of the cowling. We also received information on acoustical absorbers from AZONIC late in the program. It appears that AZONIC has better absorption coefficients than SONEX.

B.2) The exhaust system would be another area of study. The dissipative silencer used in the current study leaves much room for improvement as it only reduced the relatively high frequency noise. For a silencer to be effective it should be at least two times the length of the wavelength of the noise frequencies that are to be reduced. It is important to realize that this length is the exhaust path and that the silencer itself does not necessarily have to be that long. For example, for 125 Hz noise the wavelength is approximately 4.4 feet which would require an 8.8 foot long exhaust path. Silencer dimensions would be dependent on the frequency characteristics of the exhaust which would be related to engine noise. It is felt that a reactive silencer could be designed for this special machine.

B.3) Finally, the skirt material, location of the skirt and installation of the skirt should be studied in more detail. By isolating engine noise, track noise would also be isolated and the characteristics of the track noise would provide information for choosing the best material for a skirt. The skirt has to have

barrier capabilities yet it can not be too heavy. It also has to be tough because it will contact the snow in some circumstances and may be subject to tearing or slowing the vehicle down. One area that should be investigated is the possibility of mounting the skirt further out from the snowmobile body such that it would not interfere with track or ski action.

- C.) Once these three areas have been modified for optimum noise reduction a short series of tests should be conducted to evaluate performance and endurance of the vehicle with the noise kit modifications. At a minimum braking, acceleration and slope climbing, tests should be conducted to determine how much final horsepower the kits take away from the original vehicles performance. An endurance test of about 500 miles will also provide an indication of engine overheating problems, if any, and skirt longevity.

It is felt that by conducting a more extensive study as outlined here, the maximum amount of noise could be reduced resulting in a low noise signature for the MOST vehicle.

## **APPENDIX A**

### **Acoustic Properties Of Materials Used In Noise Kit**

<b>Dura-Sonic 5684</b>	
<b>Vinyl With 1/4" Acoustical Foam</b>	
<b>Sound Transmission Class (STC)          28 dB</b>	
<b>FREQUENCY</b>	<b>SOUND TRANSMISSION LOSS (dB)</b>
100	14
125	15
160	17
200	16
250	19
315	18
400	21
500	23
630	23
800	27
1,000	30
1,250	31
1,600	35
2,000	39
2,500	40

# Acoustic Properties of SONEX I

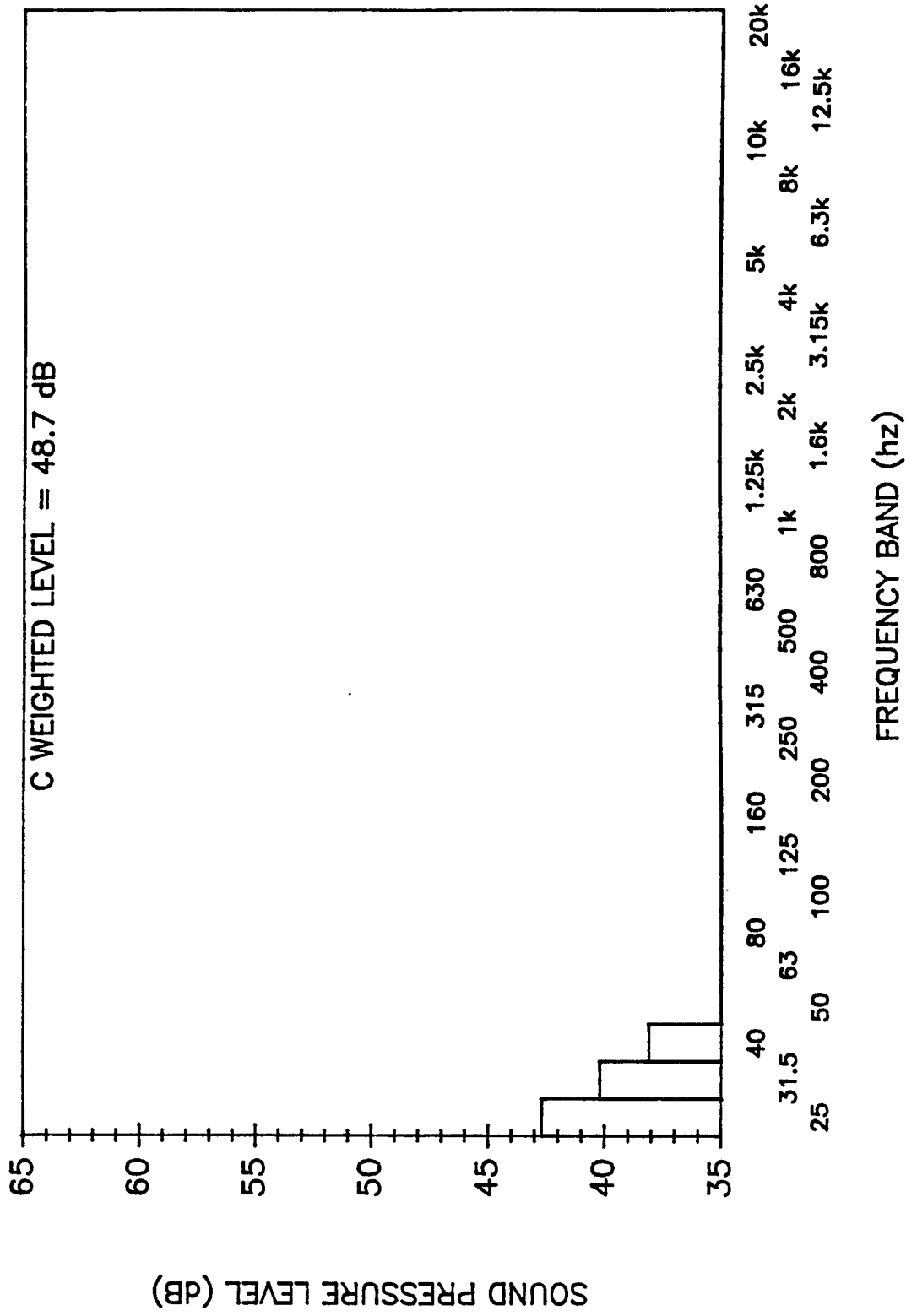
TWO INCHES THICK							
ABSORPTION COEFFICIENTS							
Thickness	125 Hz	250 Hz	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz	NRC
2 inch	0.08	0.25	0.61	0.92	0.95	0.92	0.70
3 inch	0.14	0.43	0.98	1.03	1.00	1.00	0.85
4 inch	0.20	0.70	1.06	1.01	1.01	1.00	0.95

## **APPENDIX B**

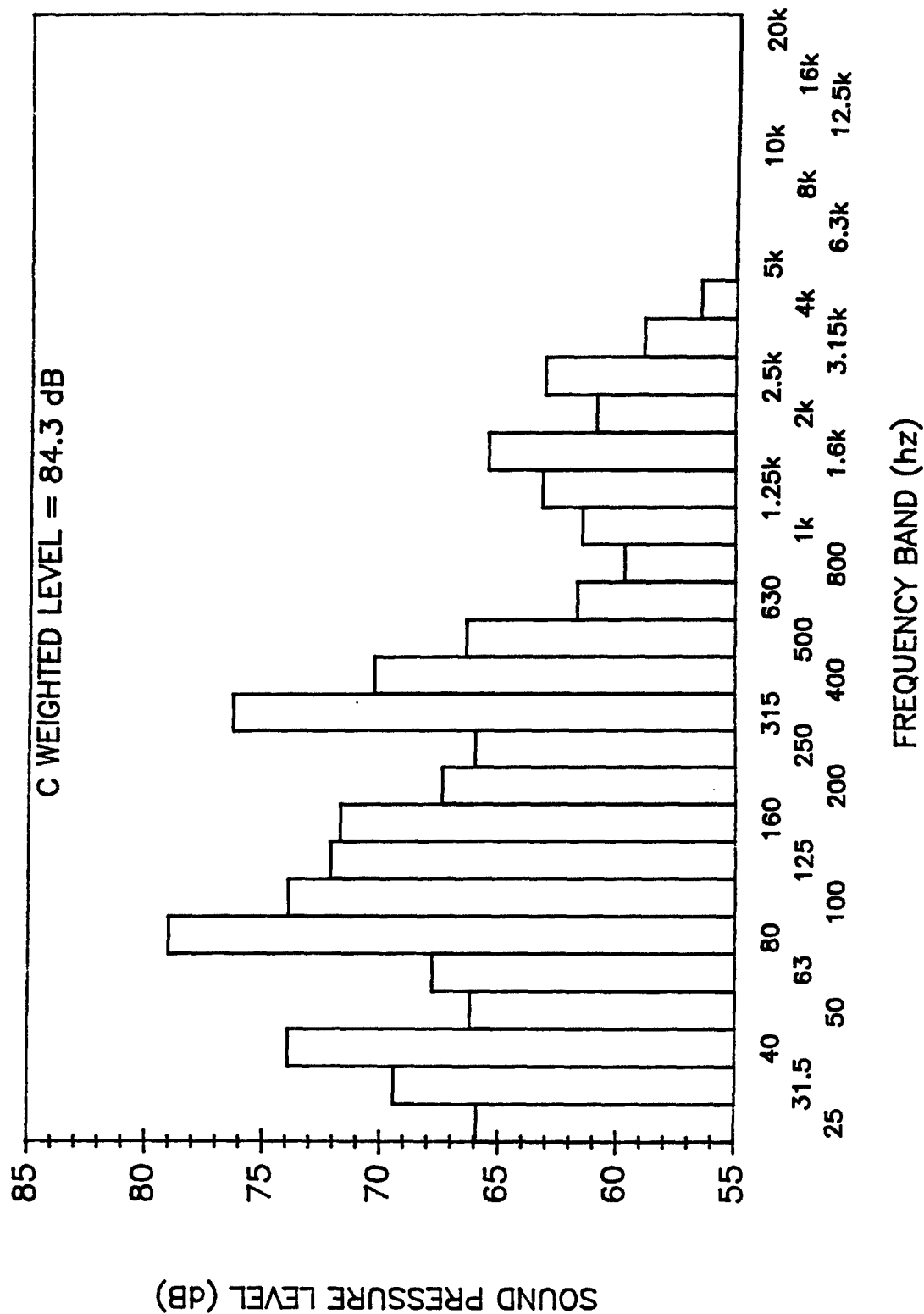
### **Octave Band Analysis Plots From Noise Kit Development Tests**



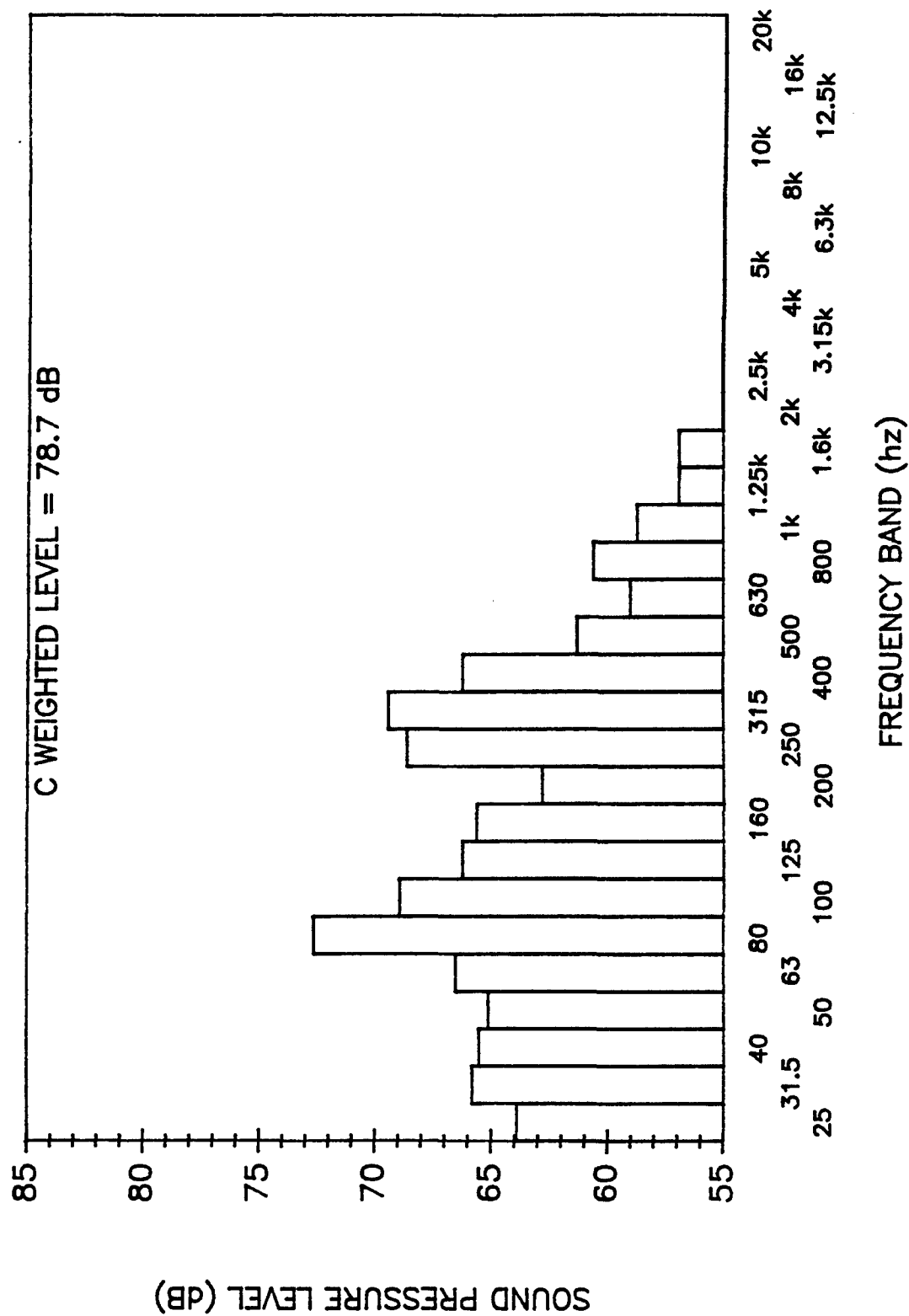
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AMBIENT TEST #3 AT THE INSTRUMENT 1 METER AWAY  
MARCH 14, 1991



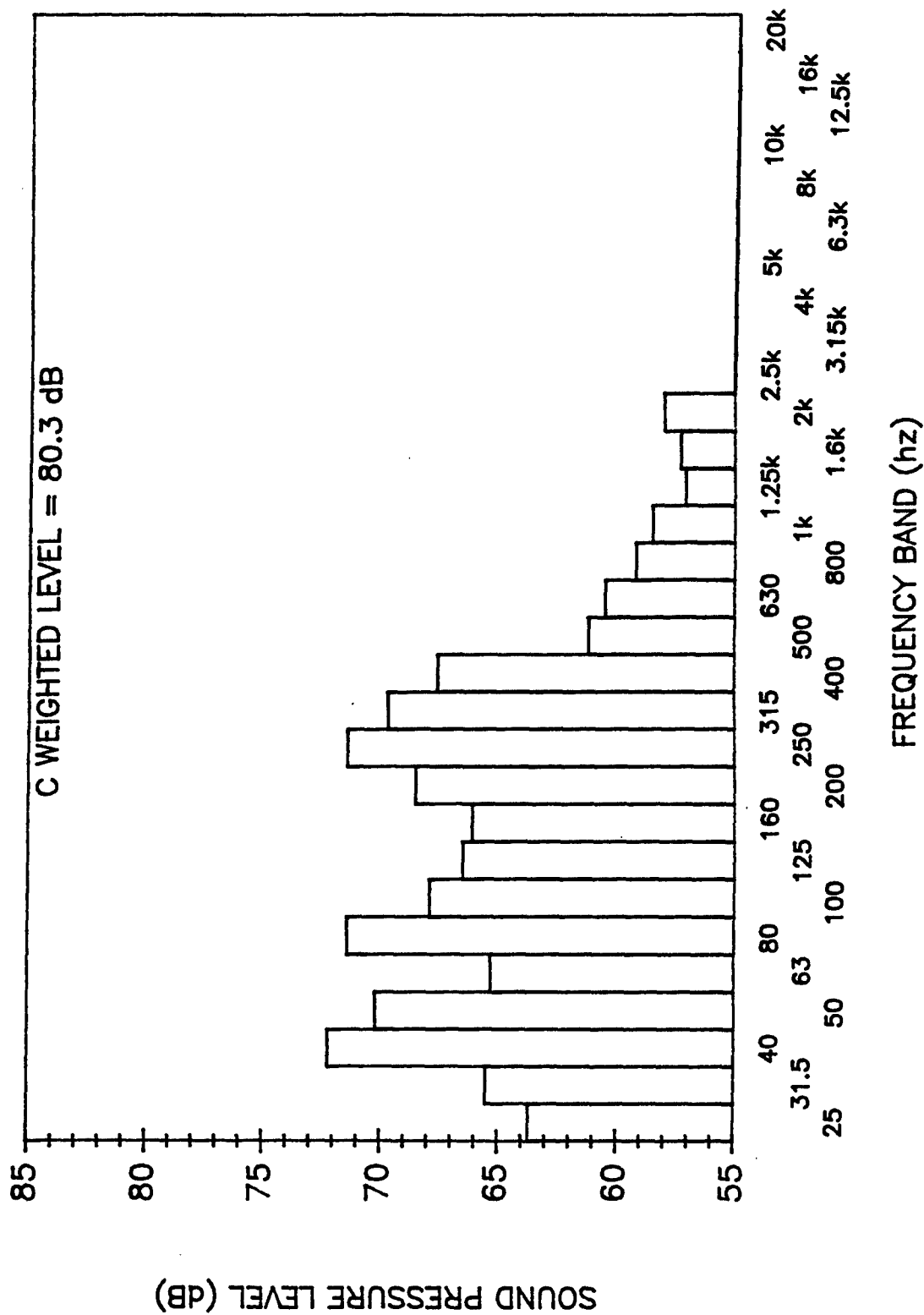
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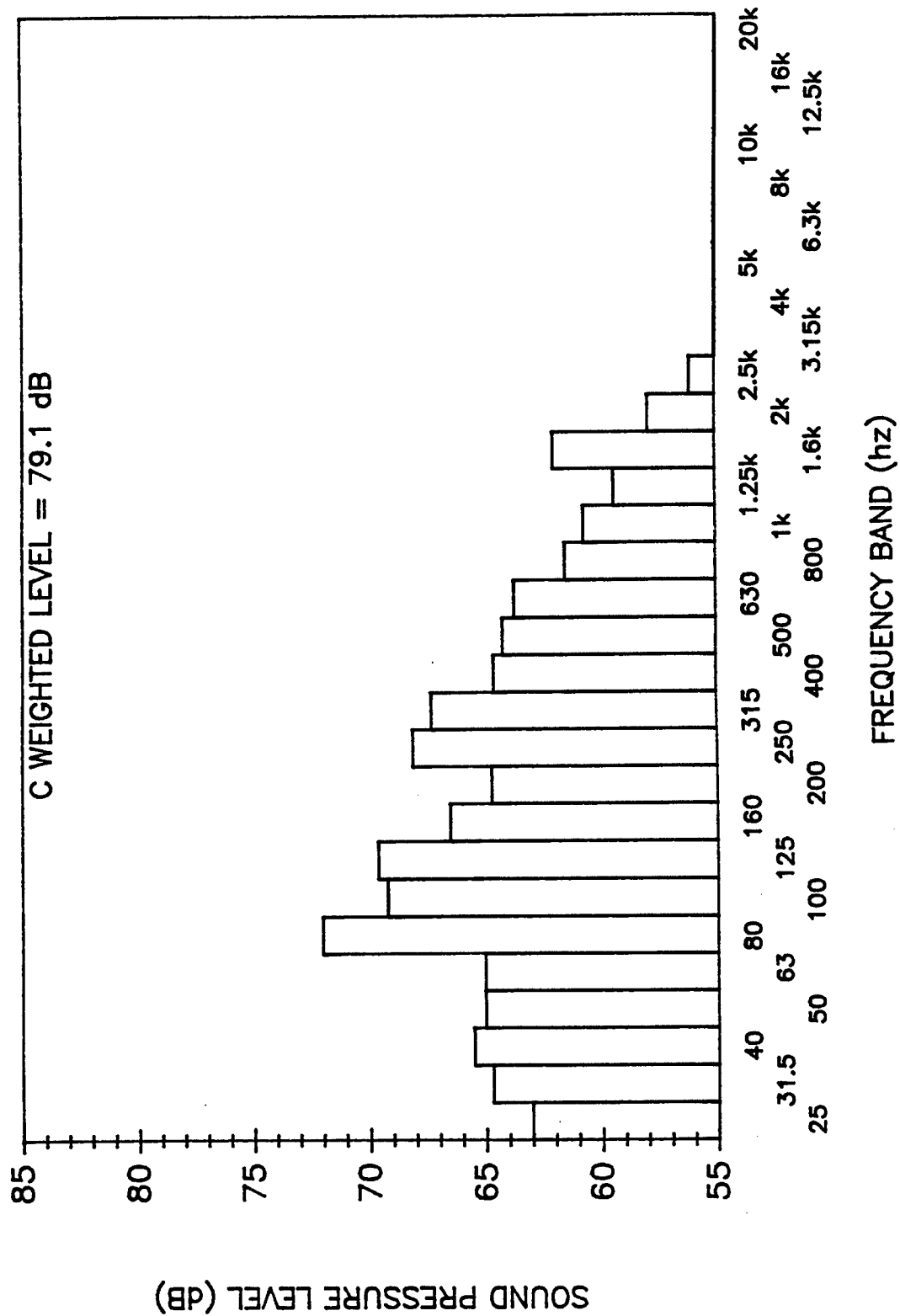
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SONEX COWL - IDLING TEST - 1 METER FROM FRONT  
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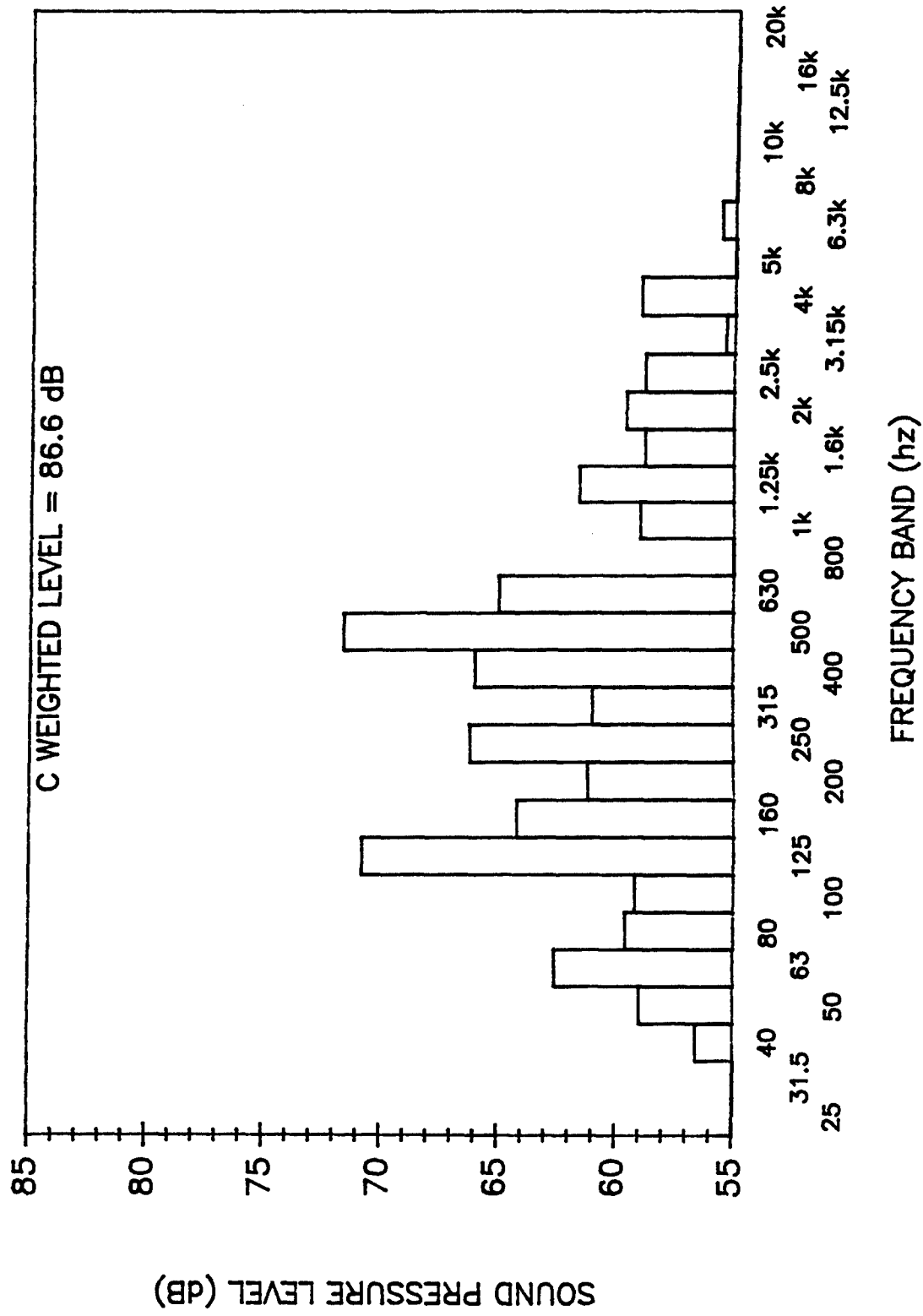
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 SONEX COWL - IDLING TEST - 1 METER FROM RIGHT  
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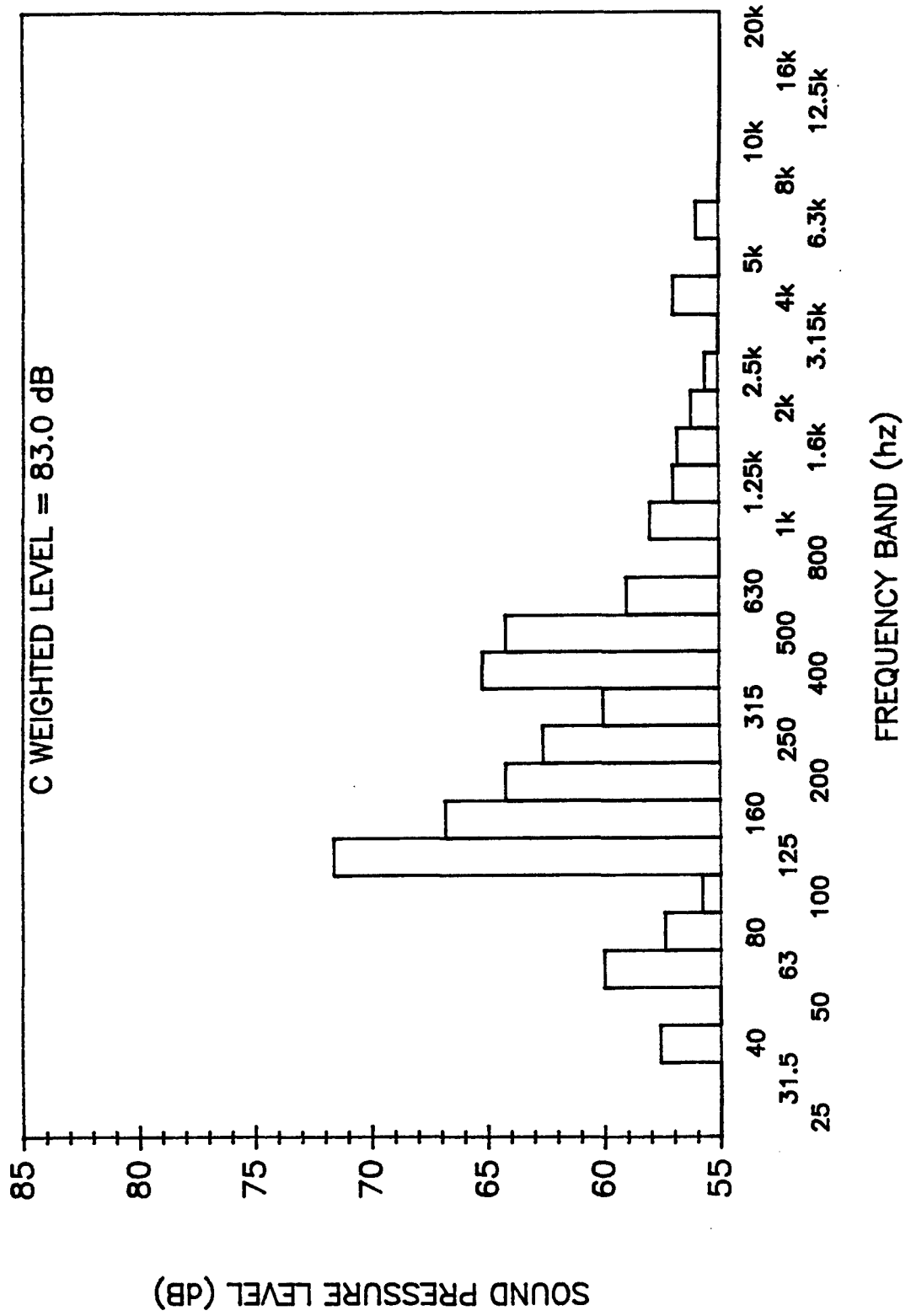
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SONEX COWL - IDLING TEST - 1 METER FROM REAR  
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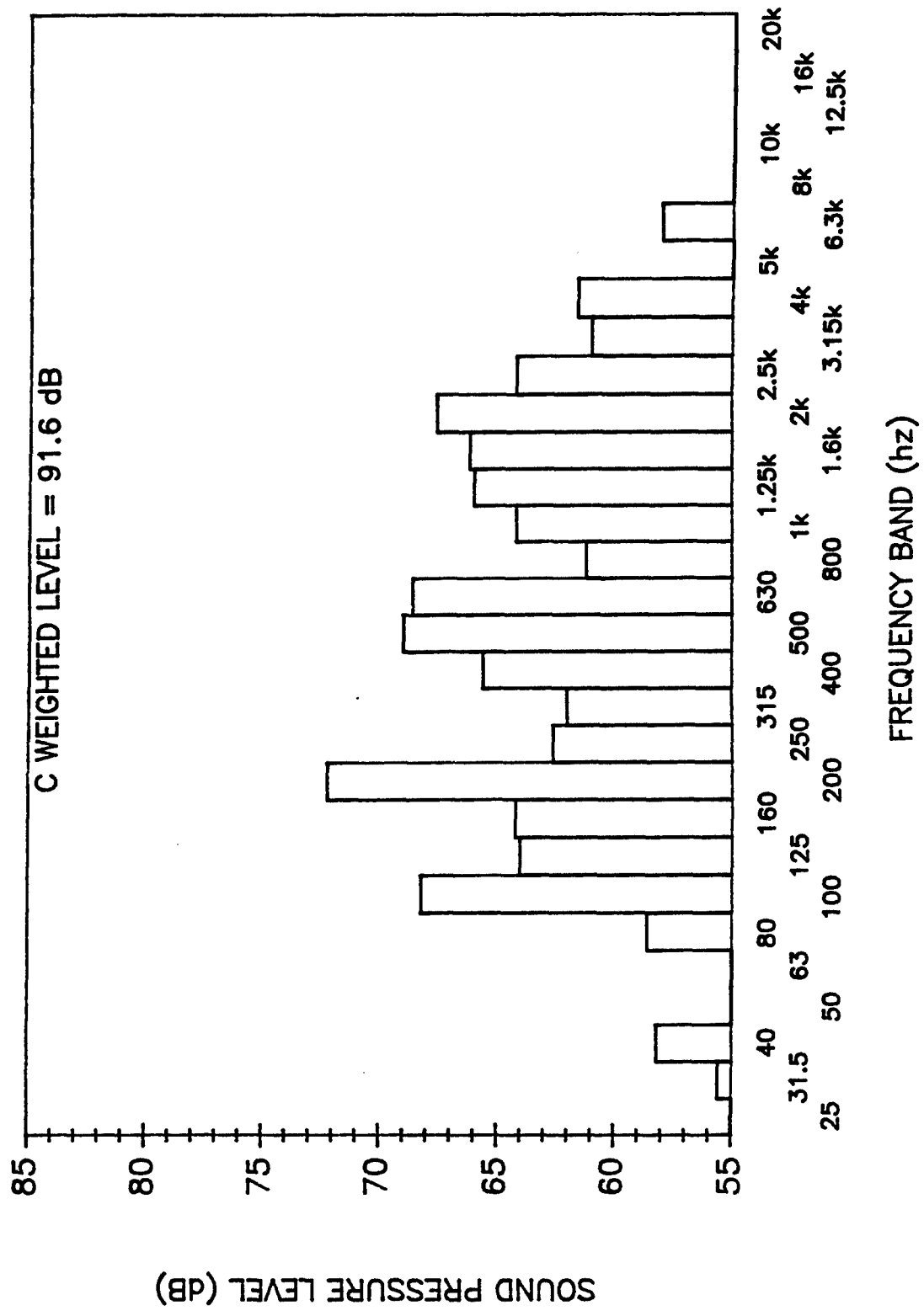
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SONEX COWL - 10 MPH PASS-BY - 1 METER FROM LEFT  
MARCH 14, 1991



YAMAHA ET400TRN SOUND PRESSURE LEVEL  
THIRD OCTAVE ANALYSIS - SLOW TIME CONSTANT  
SONEX COWL - 10 MPH PASS-BY - 1 METER FROM RIGHT  
MARCH 14, 1991

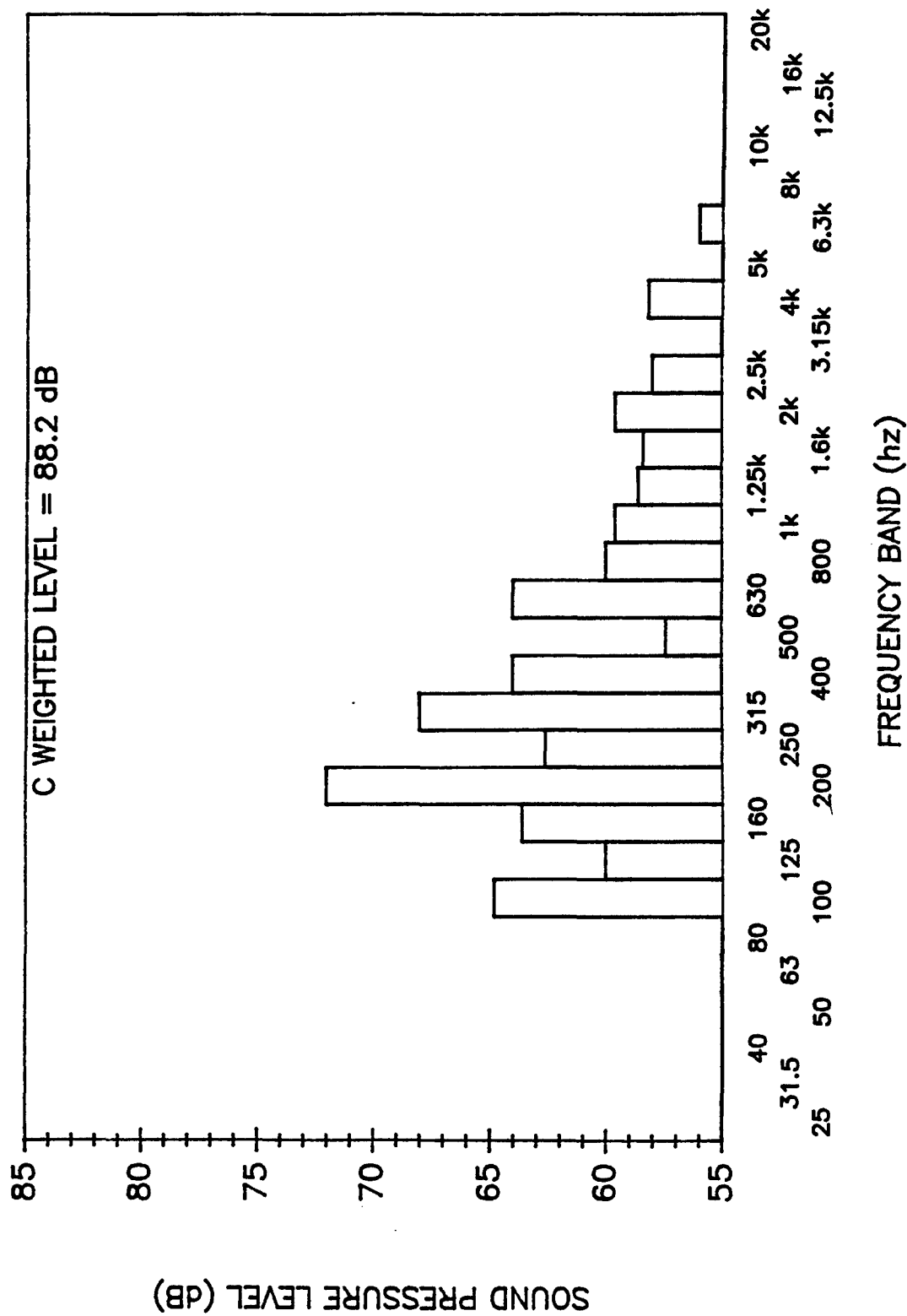


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 MARCH 14, 1991

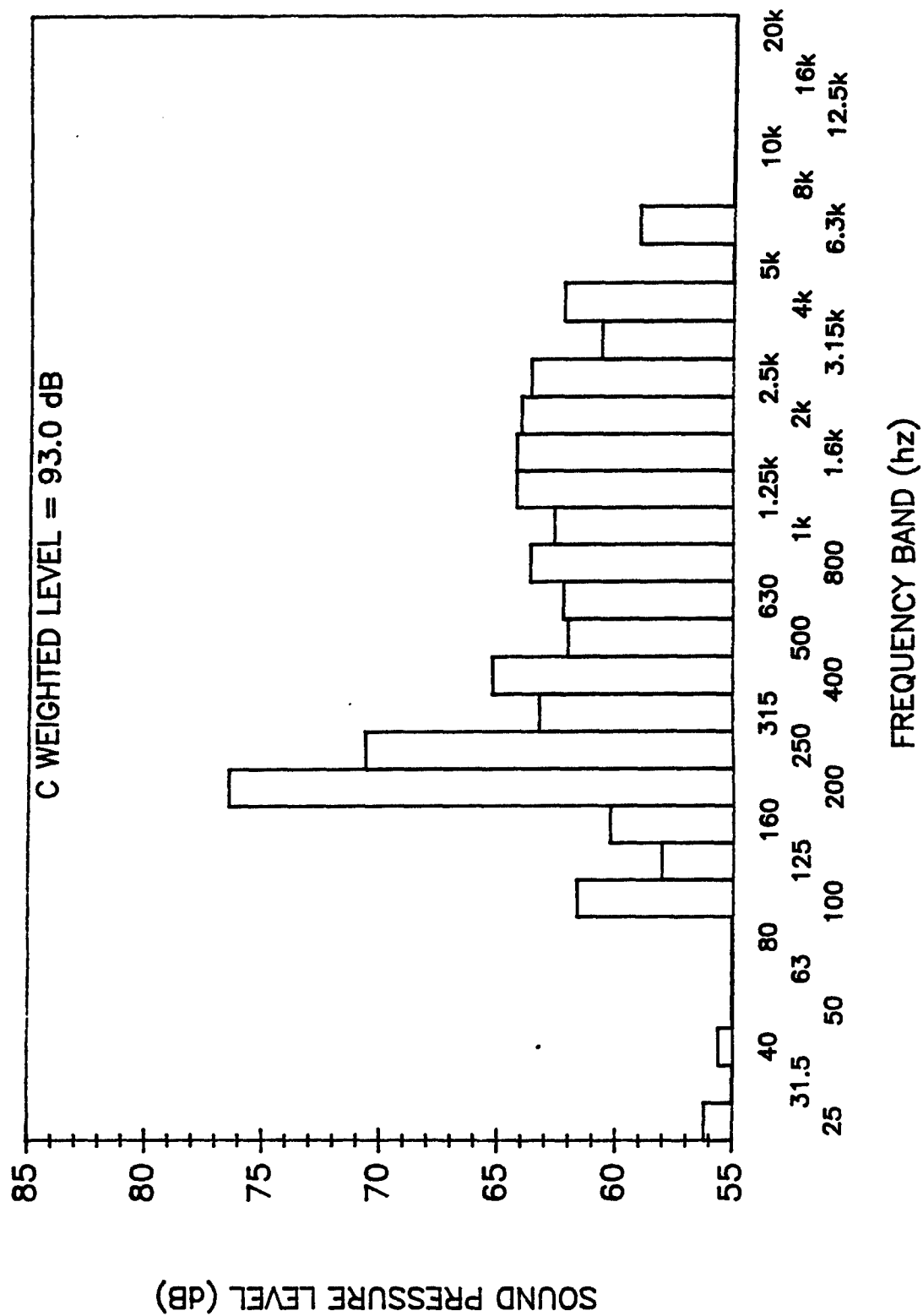




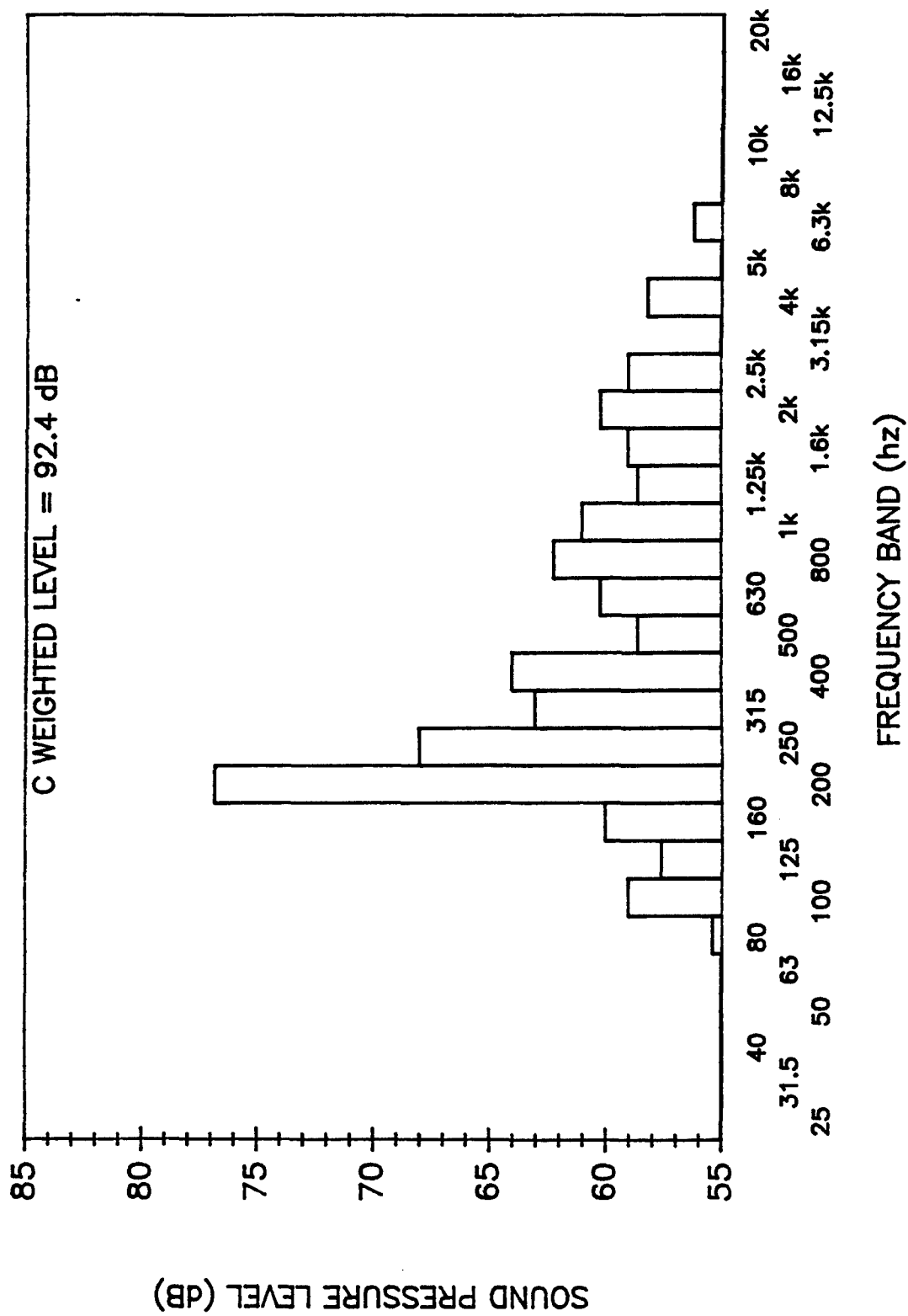
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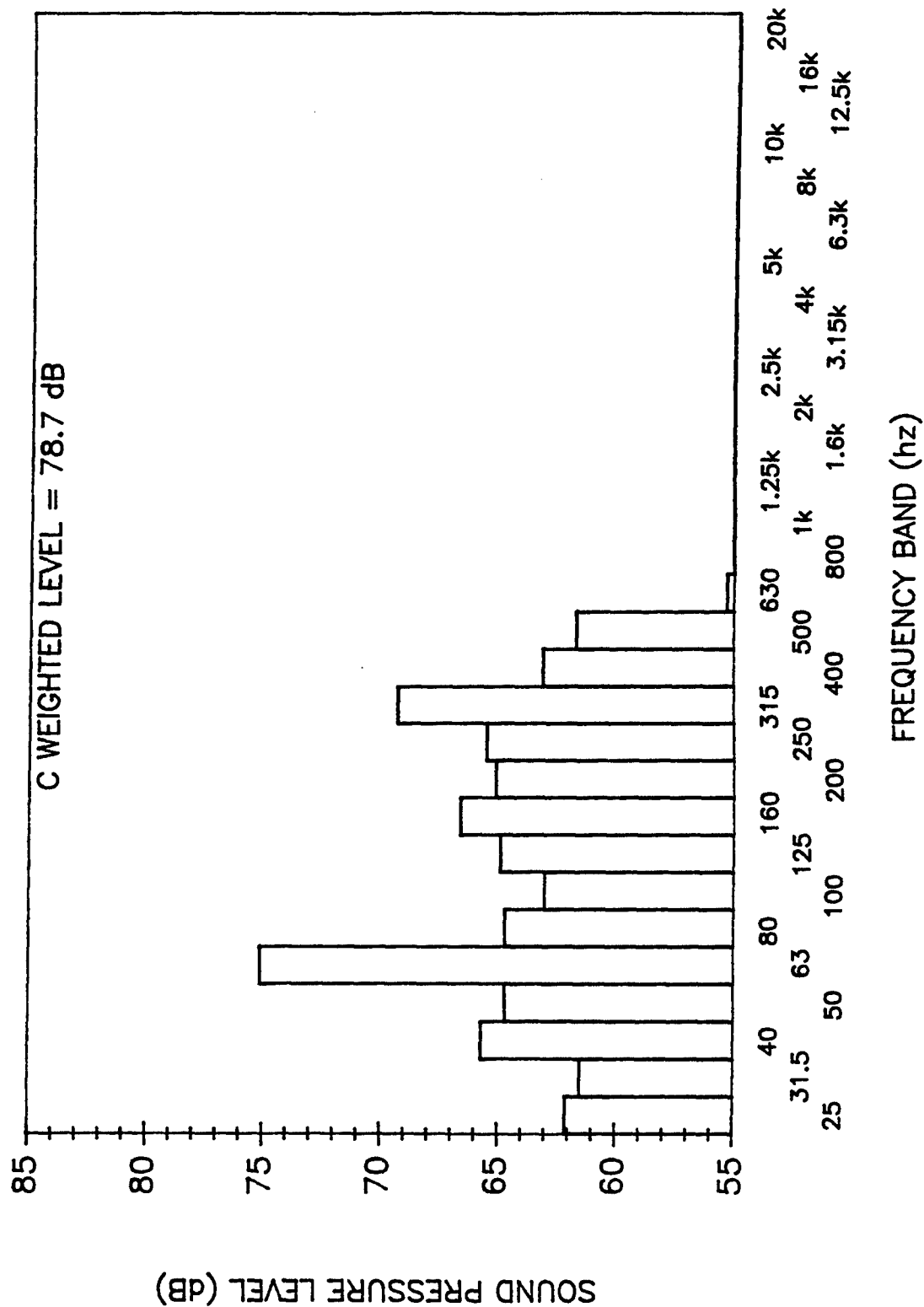
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 MARCH 14, 1991



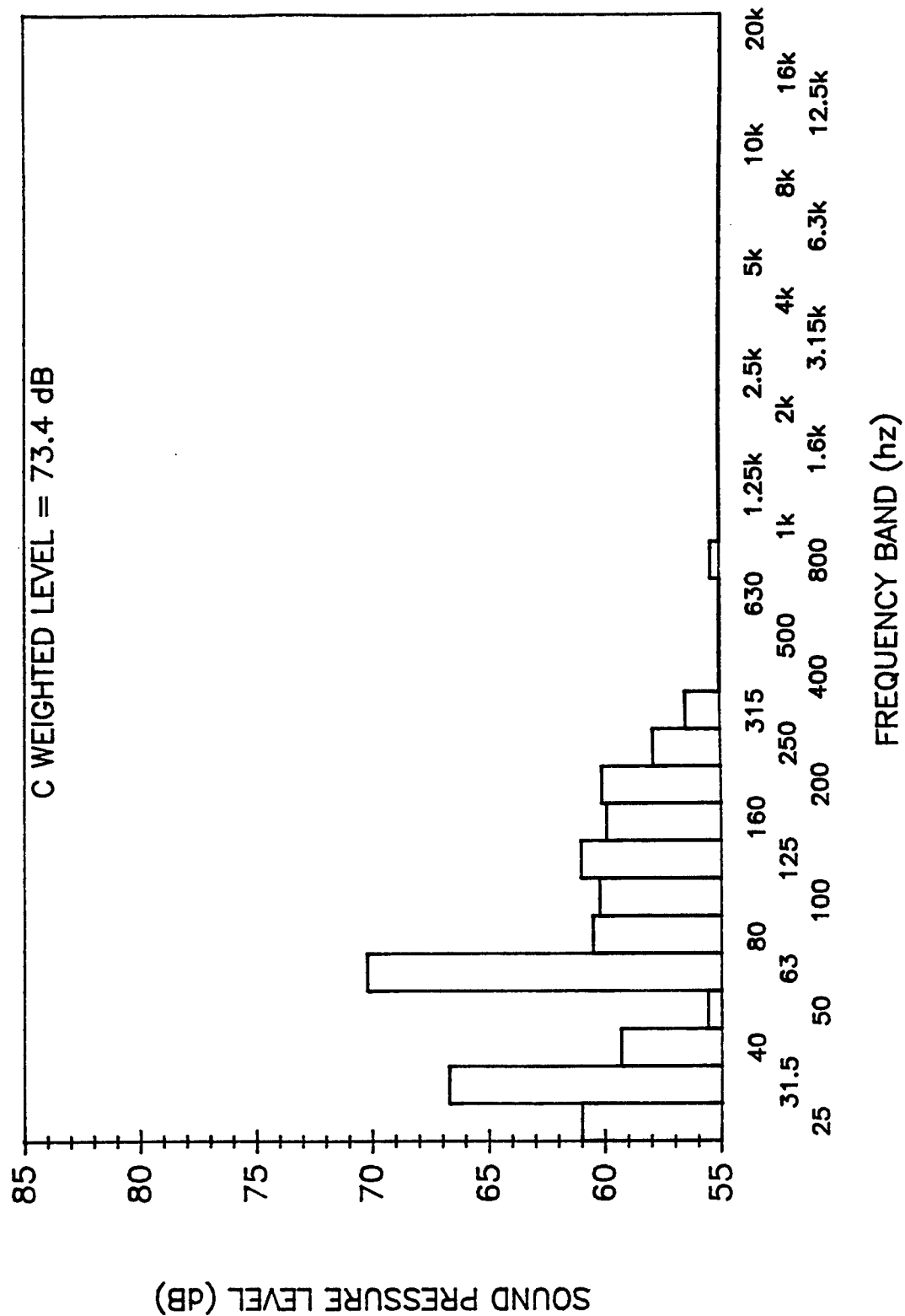
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MARCH 14, 1991



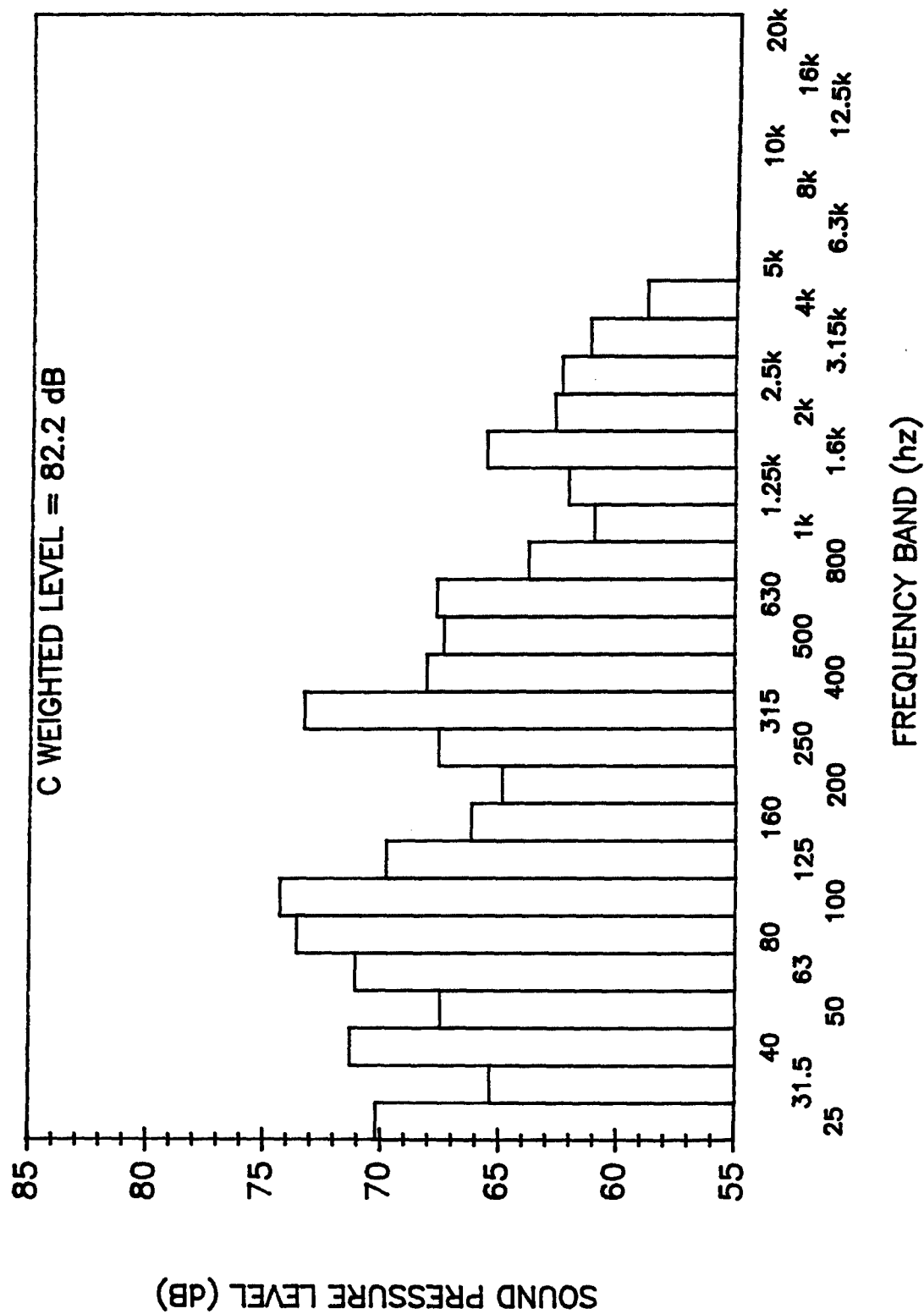
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 MARCH 14, 1991



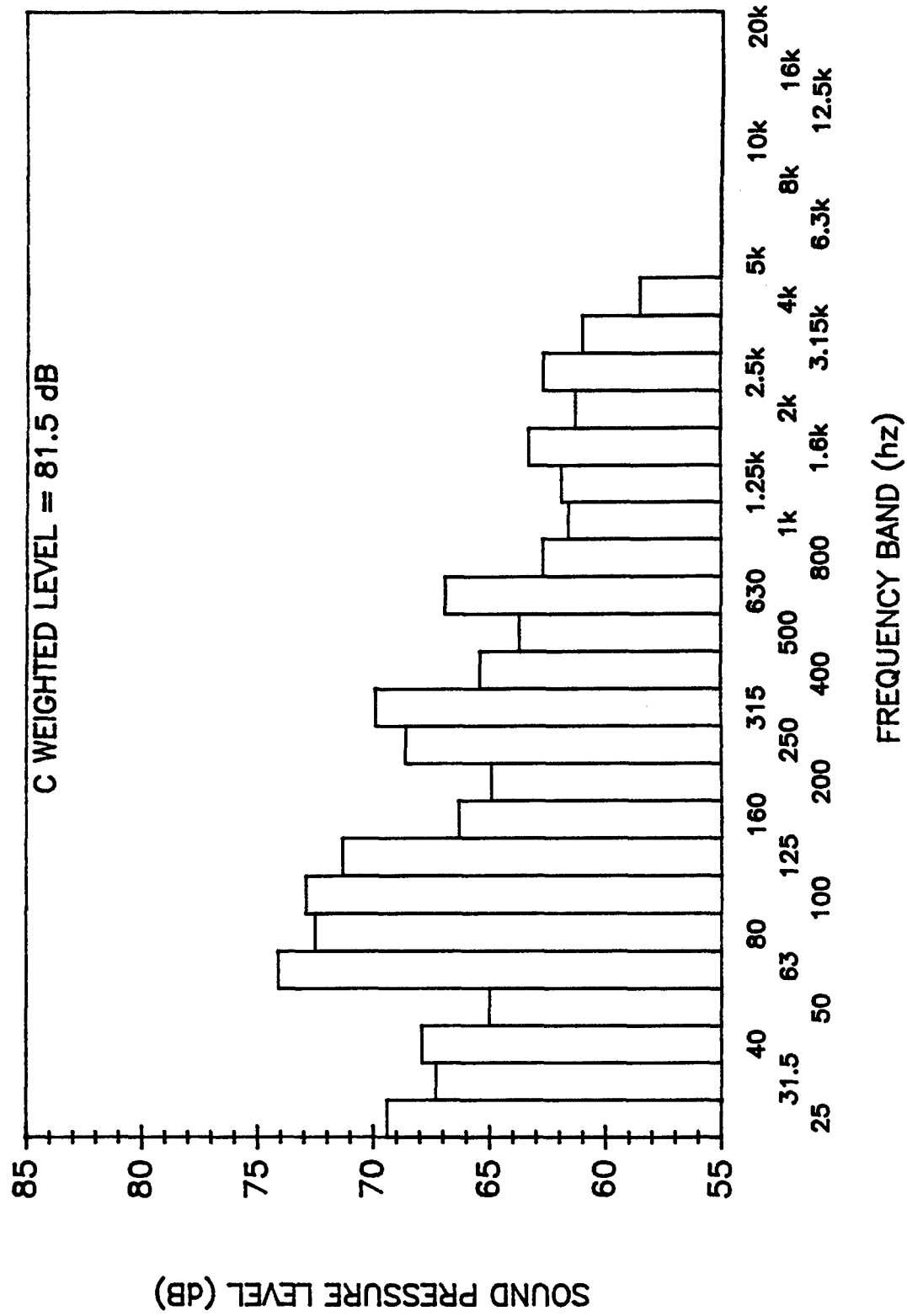
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 MARCH 14, 1991



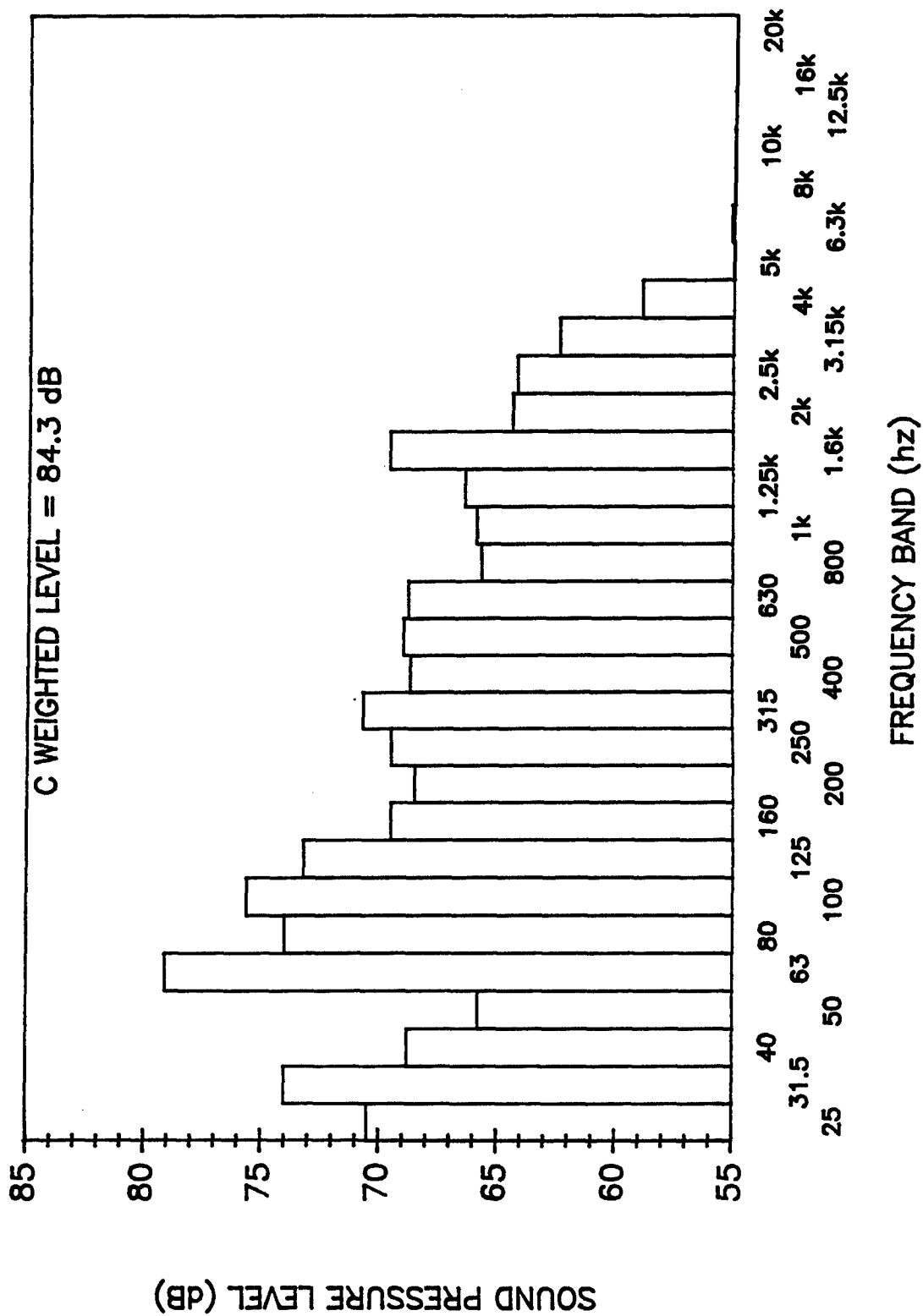
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THIRD OCTAVE ANALYSIS - SLOW TIME CONSTANT  
STOCK PACKAGE - IDLING TEST - 1 METER FROM LEFT  
MARCH 18, 1991



YAMAHA ET400TRN SOUND PRESSURE LEVEL  
 THIRD OCTAVE ANALYSIS - SLOW TIME CONSTANT  
 STOCK PACKAGE - IDLING TEST - 1 METER FROM FRONT  
 MARCH 18, 1991

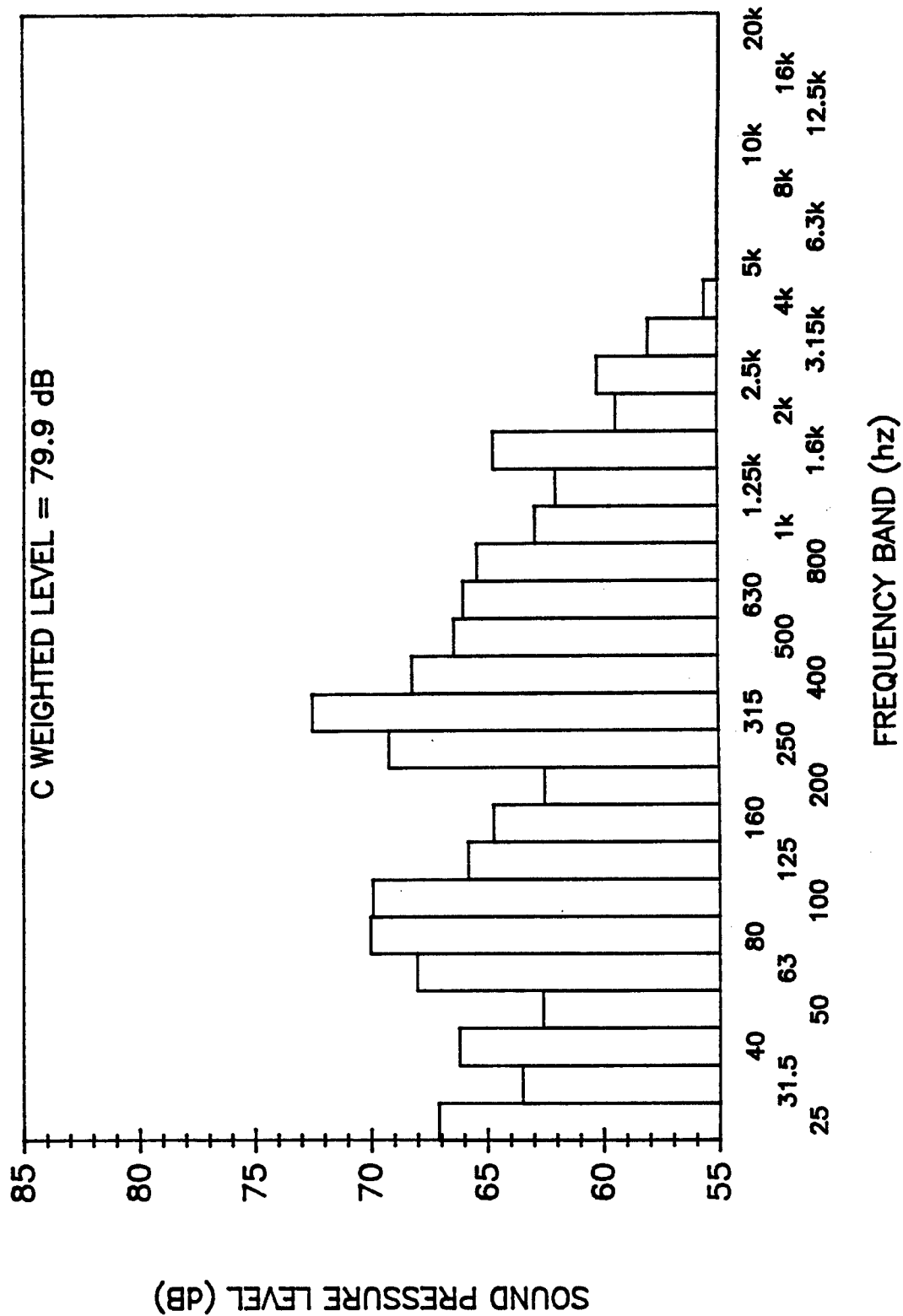


YAMAHA ET400TRN SOUND PRESSURE LEVEL  
THIRD OCTAVE ANALYSIS -- SLOW TIME CONSTANT  
STOCK PACKAGE -- IDLING TEST -- 1 METER FROM RIGHT  
MARCH 18, 1991

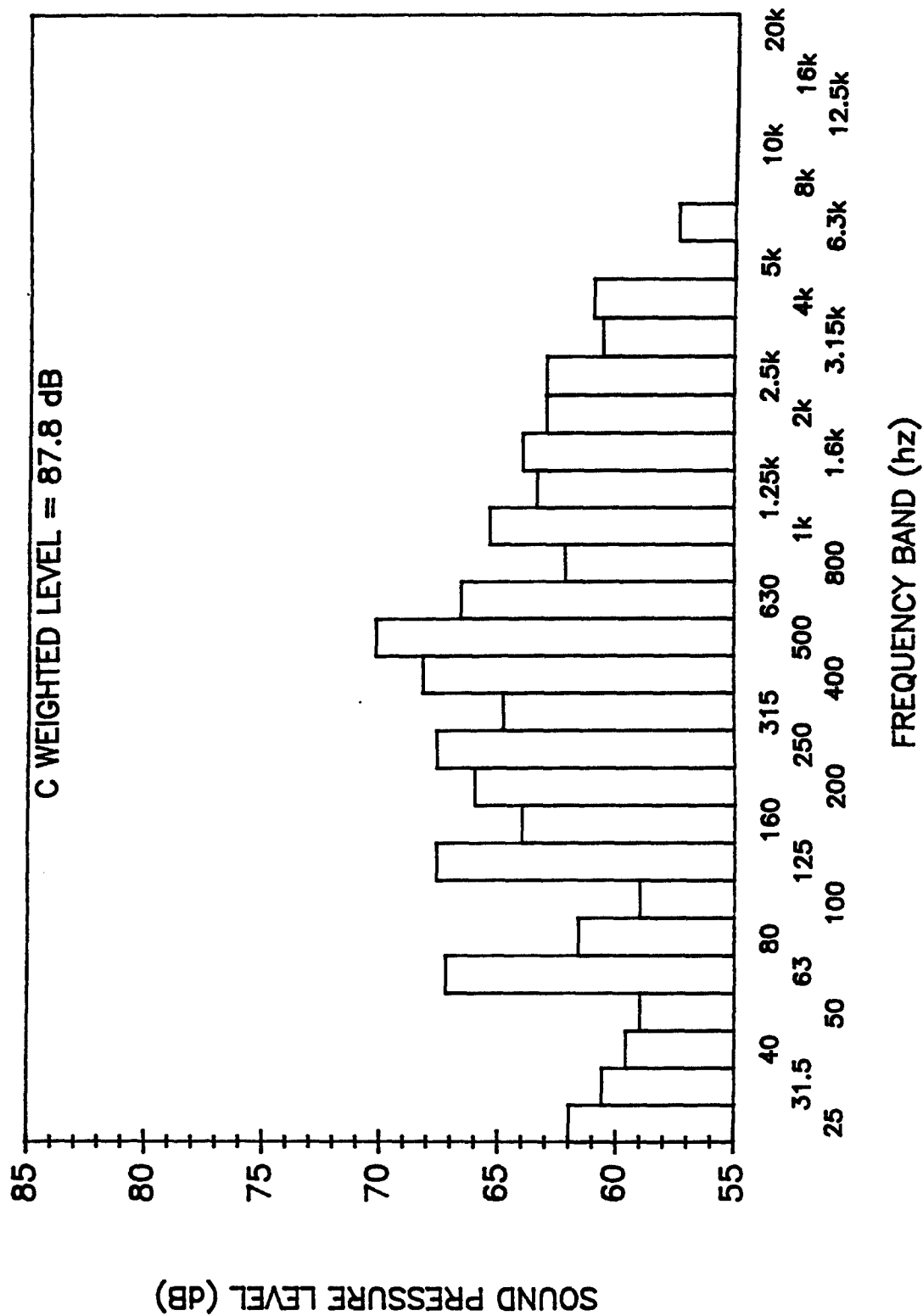




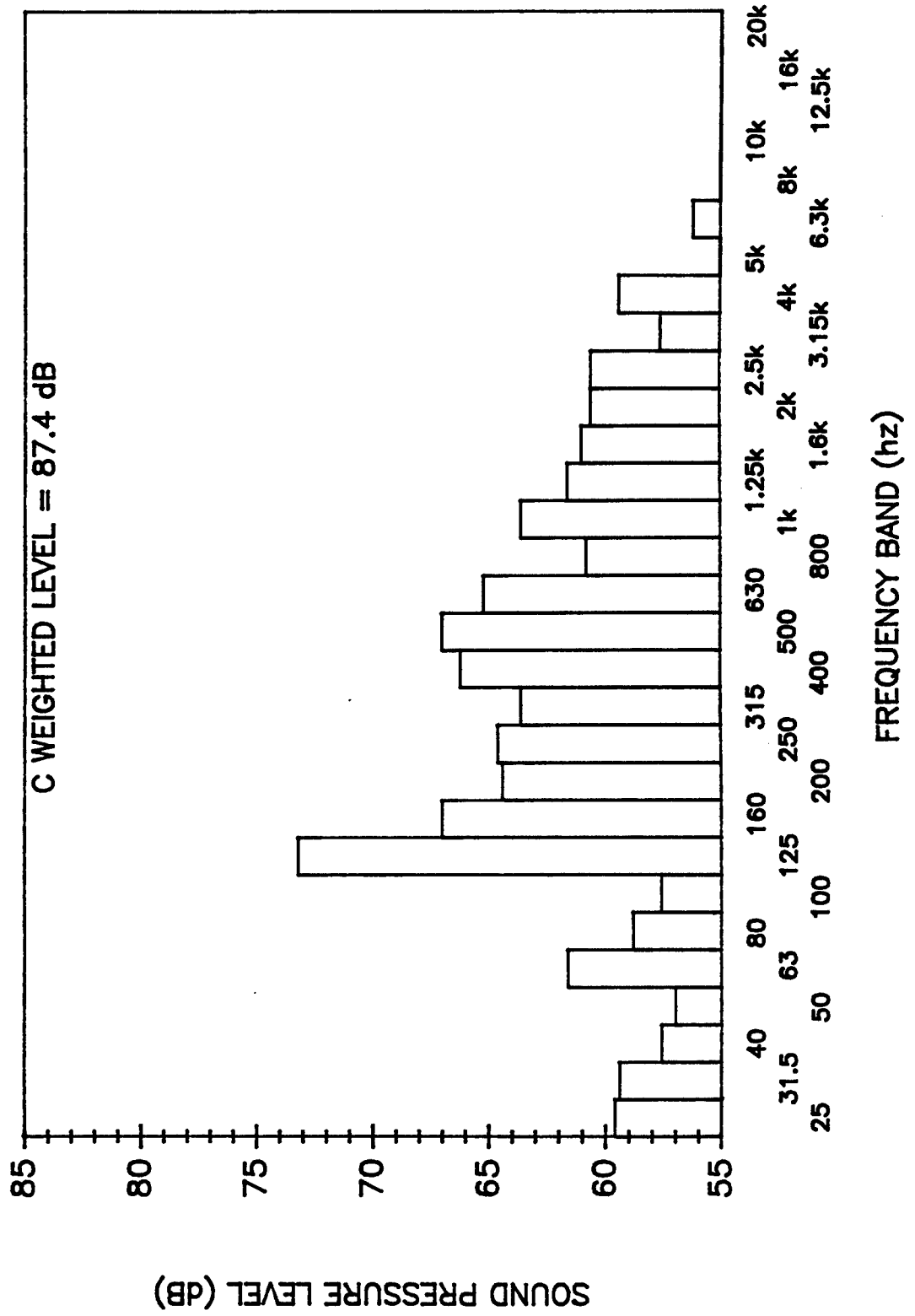
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STOCK PACKAGE — IDLING TEST — 1 METER FROM REAR  
MARCH 18, 1991



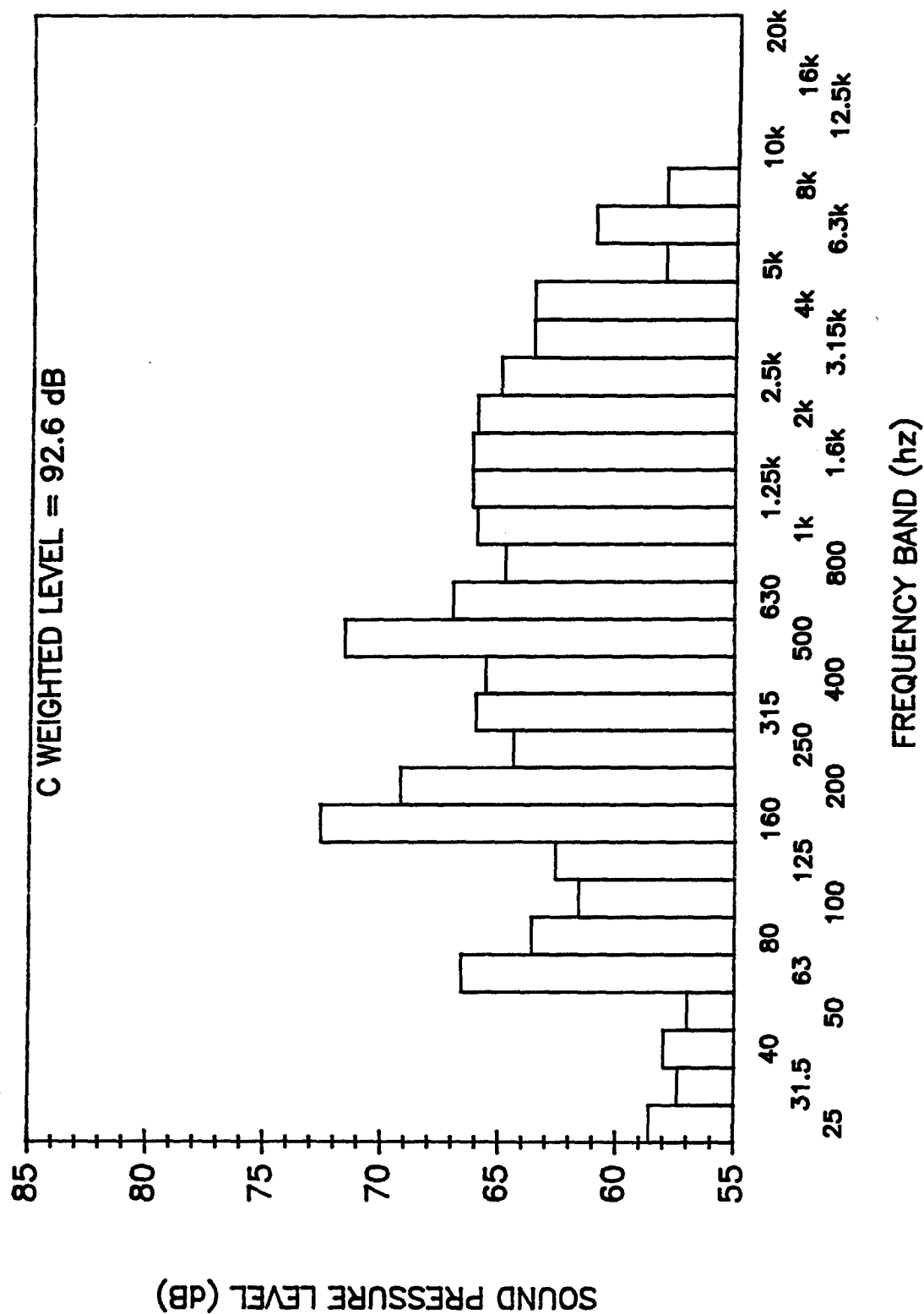
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 MARCH 18, 1991



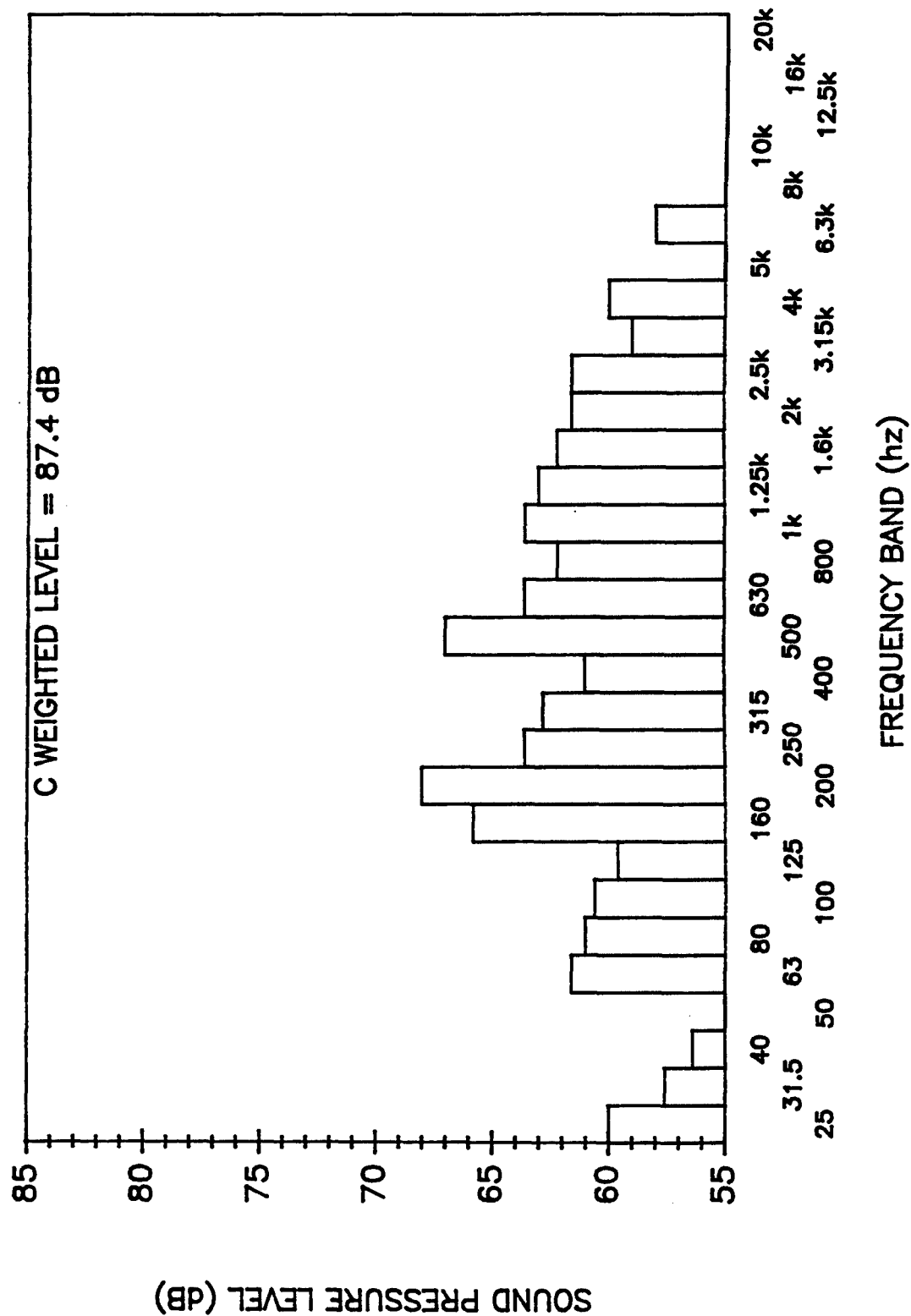
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 STOCK PACKAGE - 10 MPH PASS-BY - 1 METER FROM RIGHT  
 MARCH 18, 1991



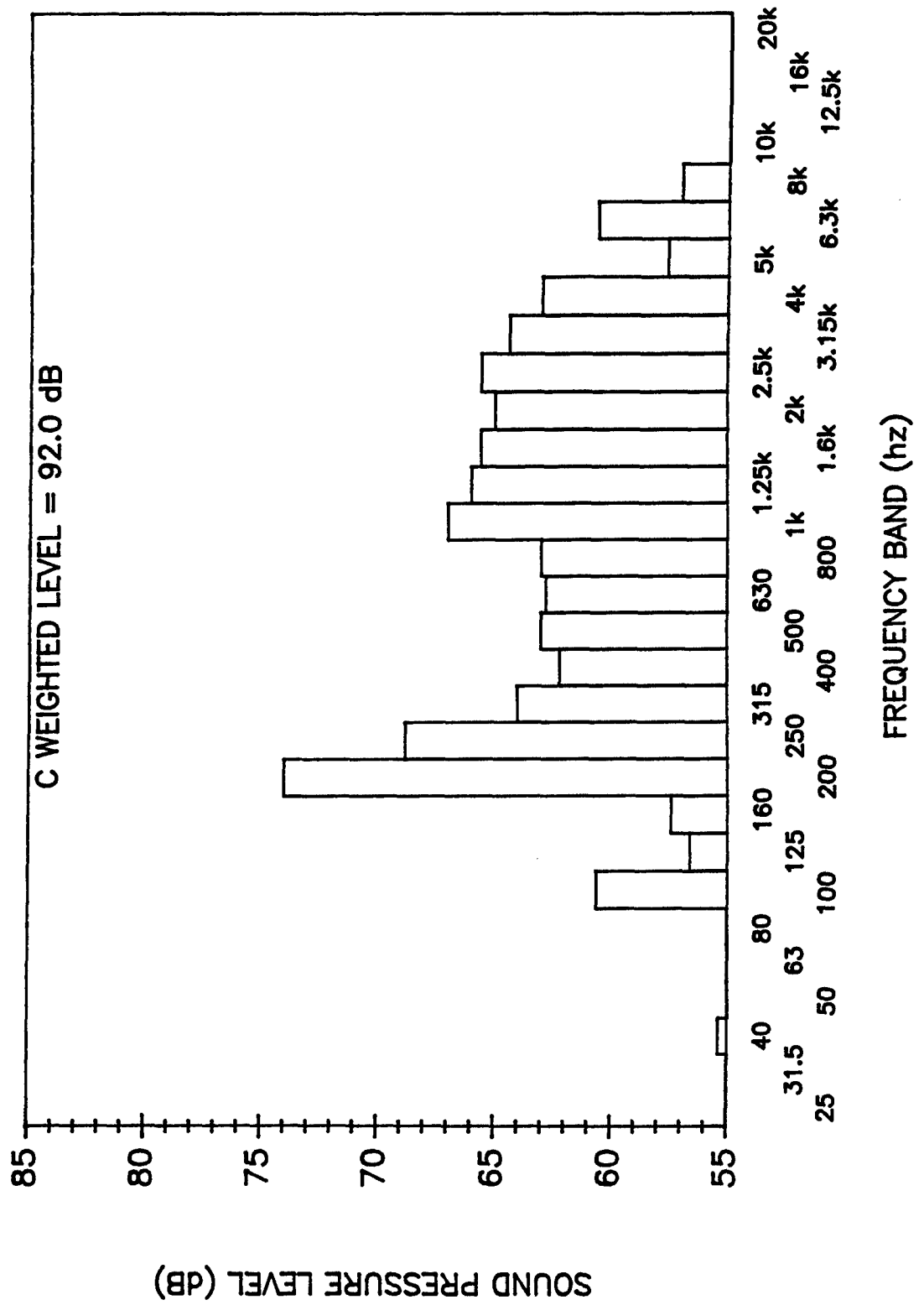
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 STOCK PACKAGE - 20 MPH PASS-BY - 1 METER FROM LEFT  
 MARCH 18, 1991



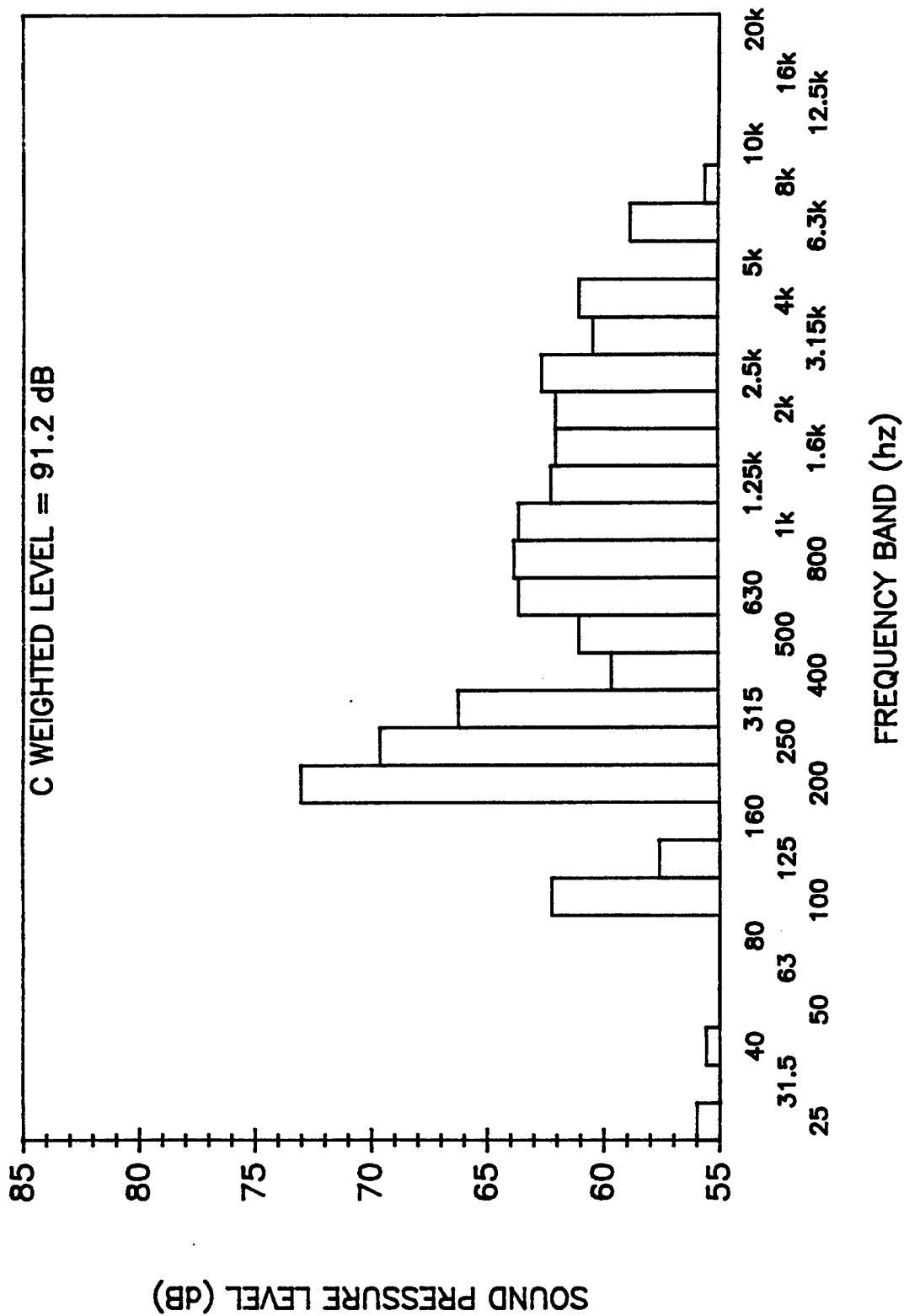
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MARCH 18, 1991



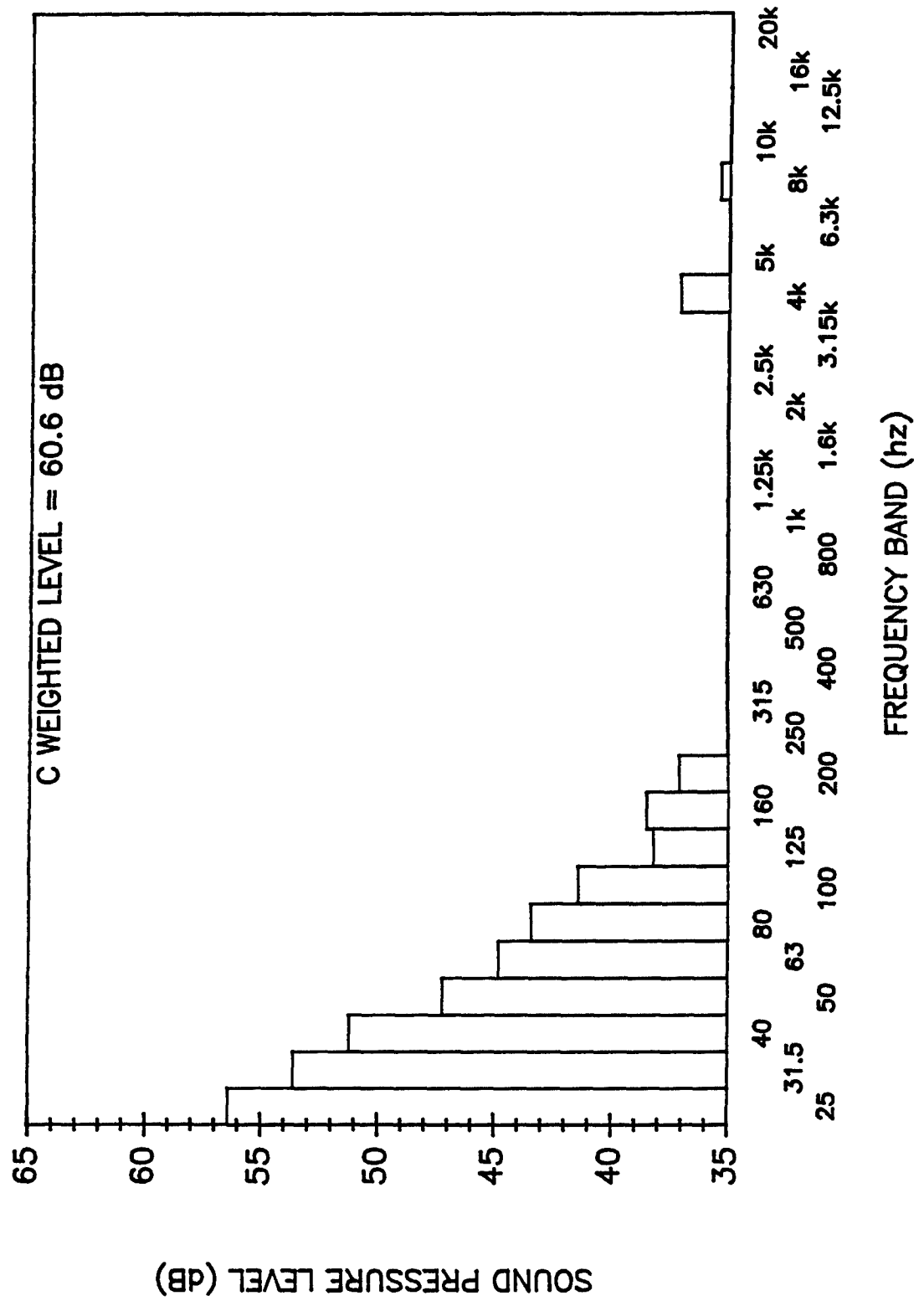
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STOCK PACKAGE - 30 MPH PASS-BY - 1 METER FROM LEFT  
MARCH 18, 1991



YAMAHA ET400TRN SOUND PRESSURE LEVEL  
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STOCK PACKAGE - 30 MPH PASS-BY - 1 METER FROM RIGHT  
MARCH 18, 1991

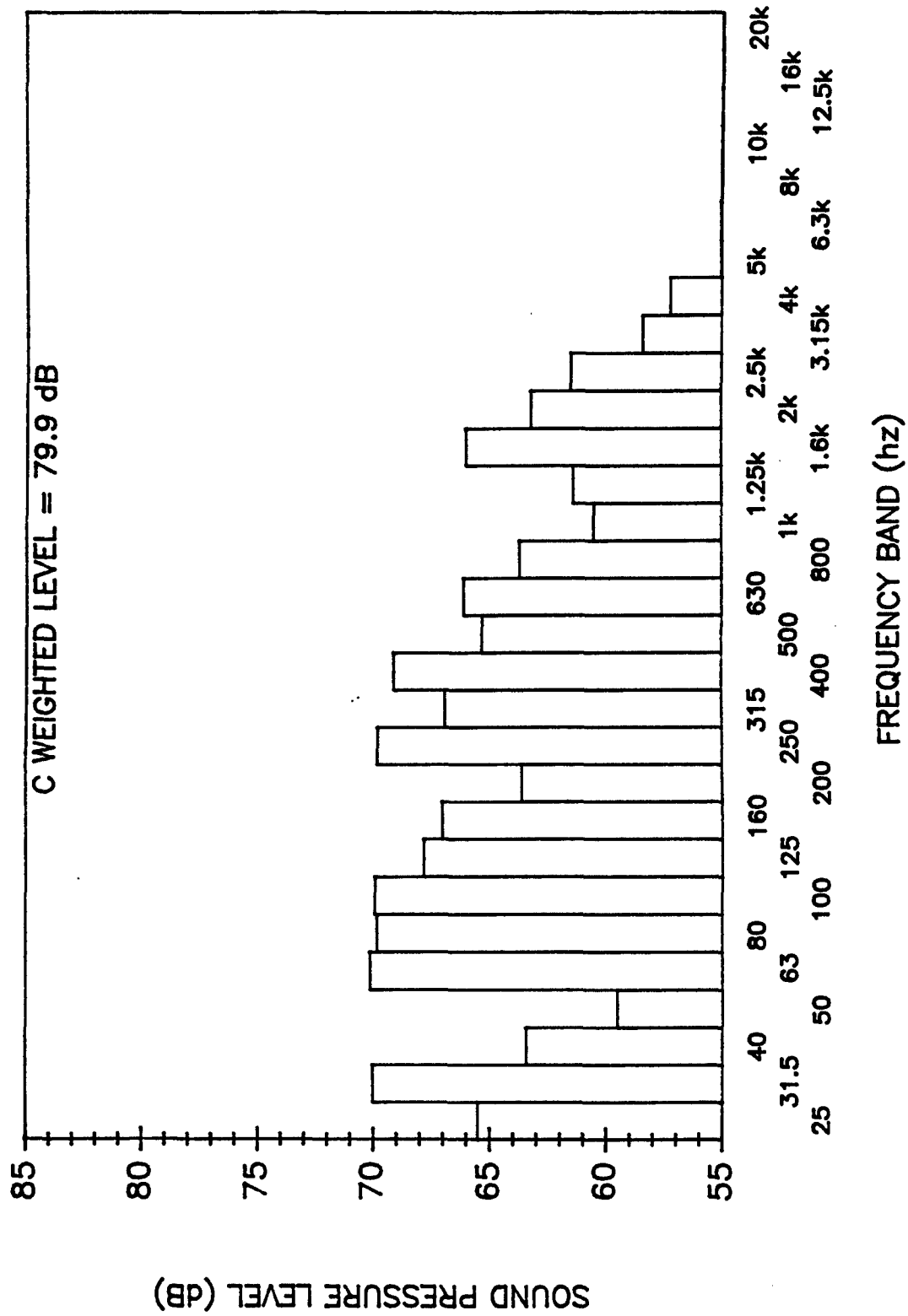


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AMBIENT TEST #2 AT THE INSTRUMENT 1 METER AWAY  
MARCH 18, 1991

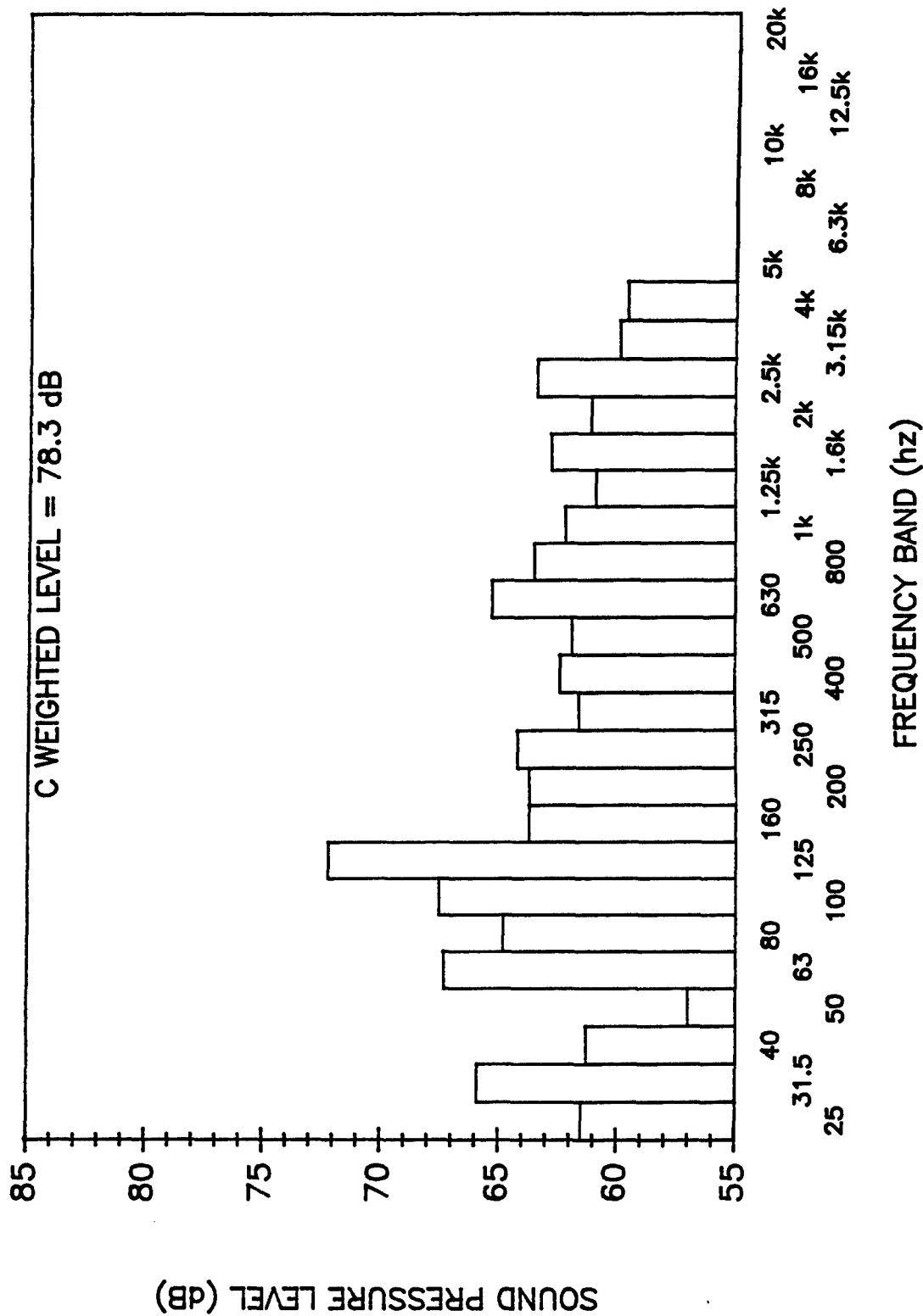




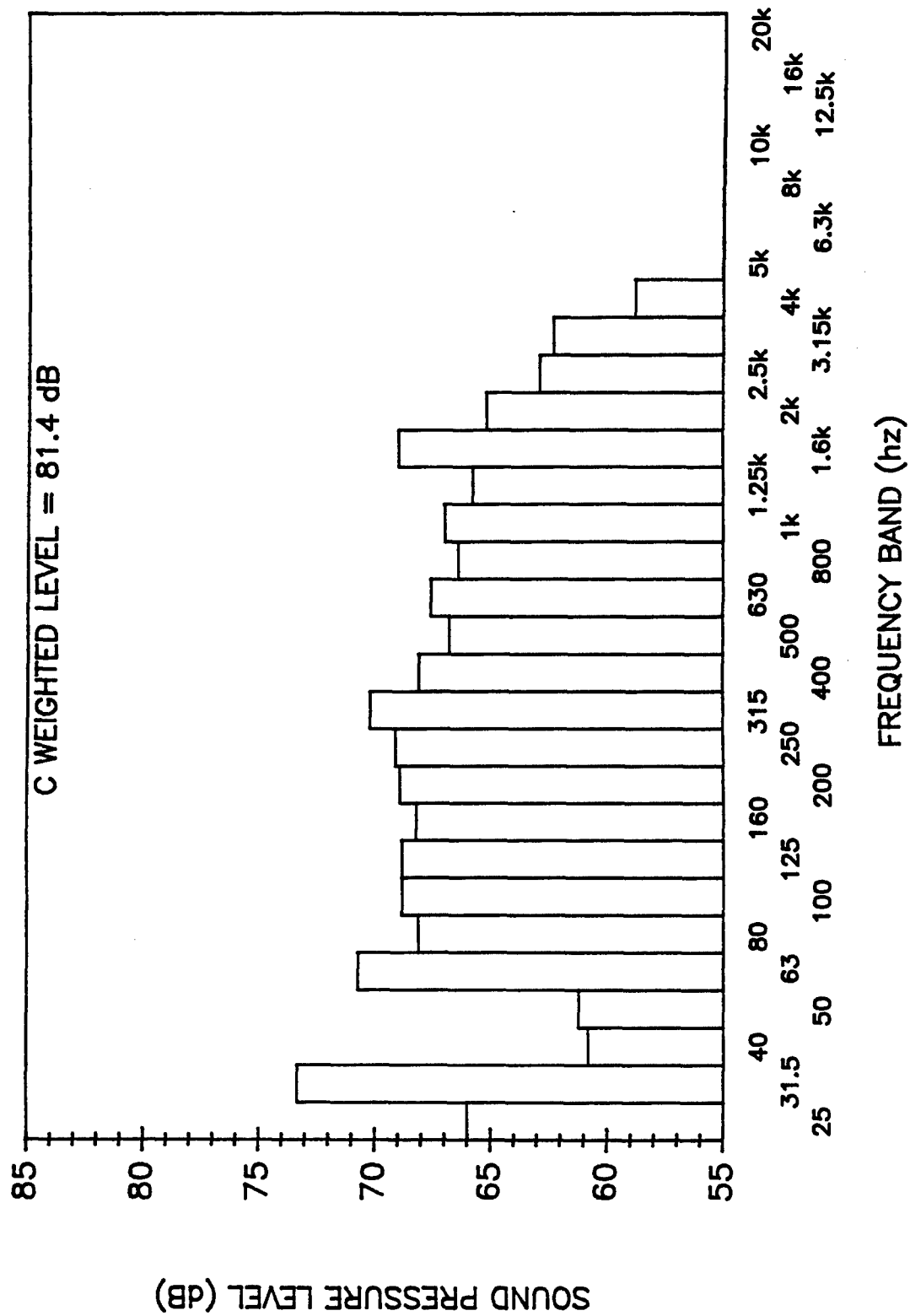
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 SMALL SILENCER - IDLING TEST - 1 METER FROM LEFT  
 MARCH 18, 1991



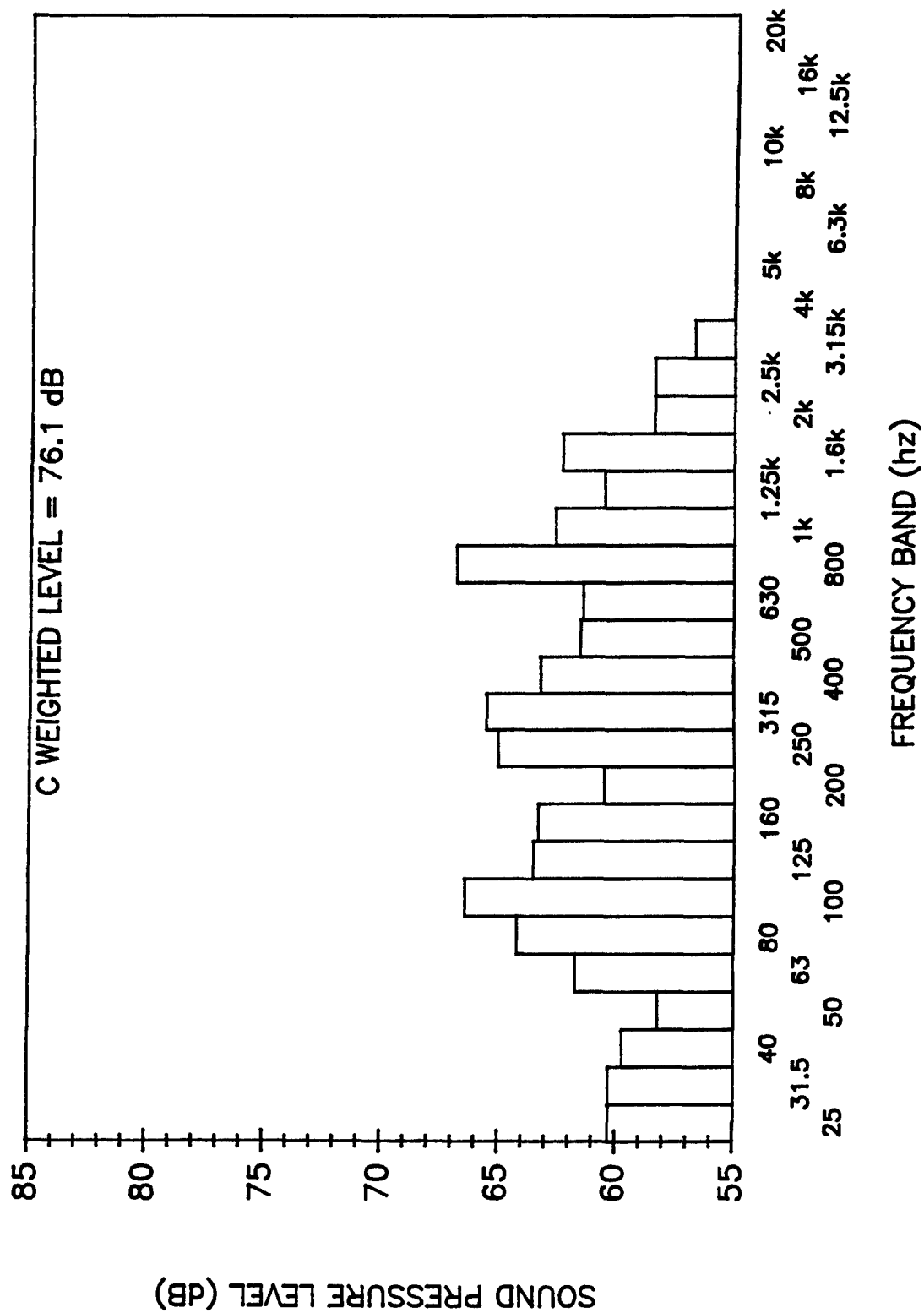
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 THIRD OCTAVE ANALYSIS - SLOW TIME CONSTANT  
 SMALL SILENCER - IDLING TEST - 1 METER FROM FRONT  
 MARCH 18, 1991



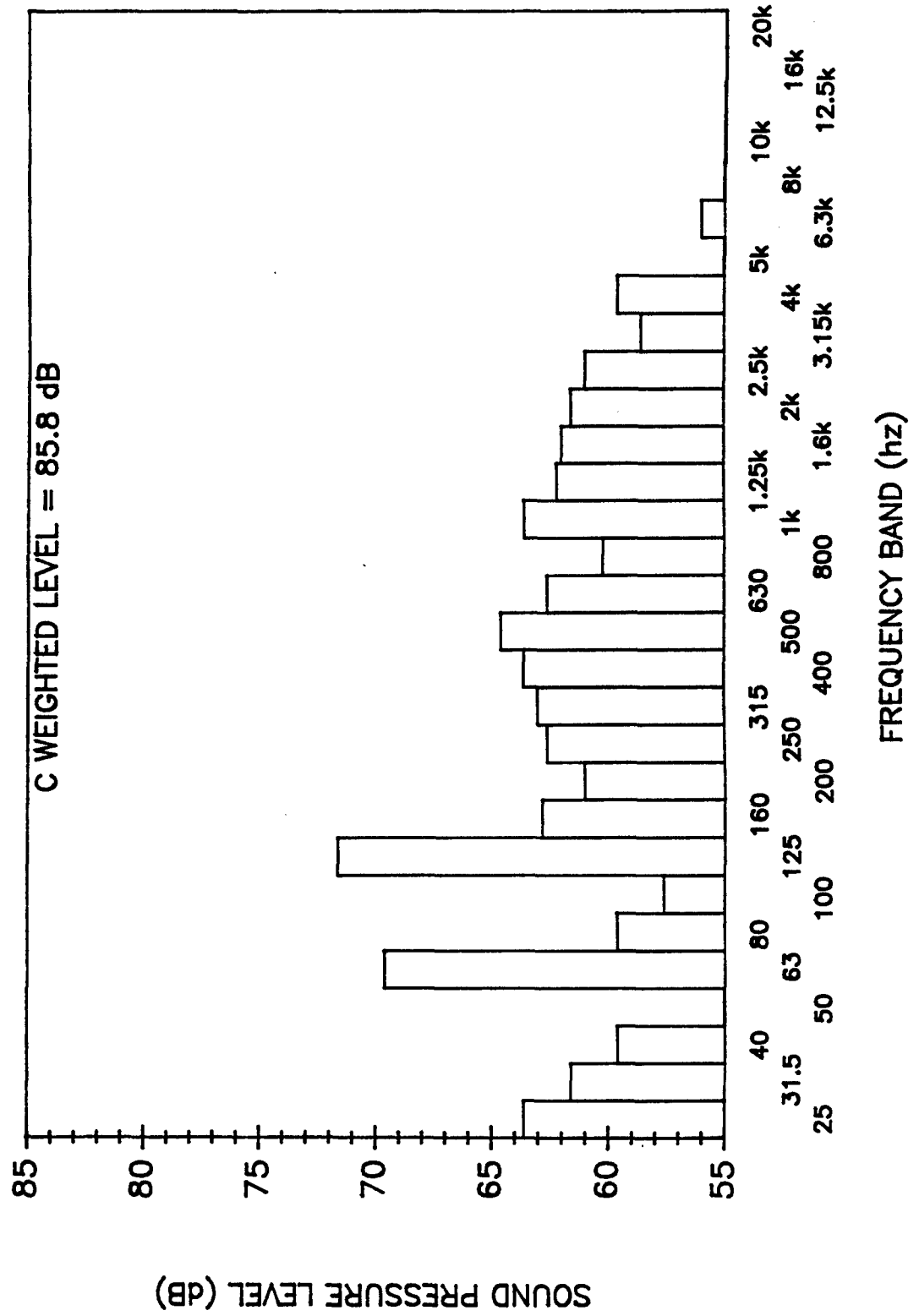
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 SMALL SILENCER - IDLING TEST - 1 METER FROM RIGHT  
 MARCH 18, 1991



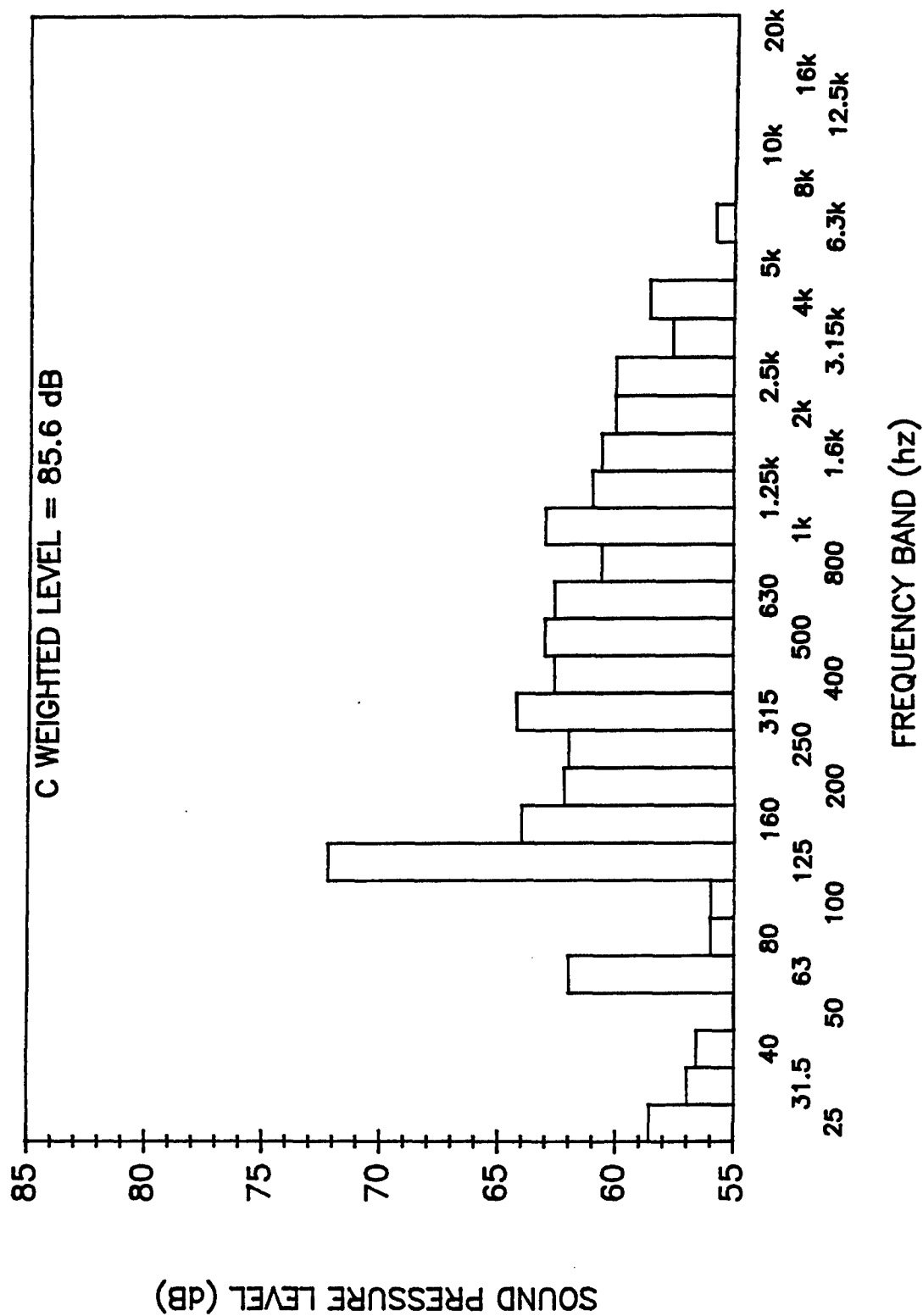
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SMALL SILENCER - IDLING TEST - 1 METER FROM REAR  
MARCH 18, 1991



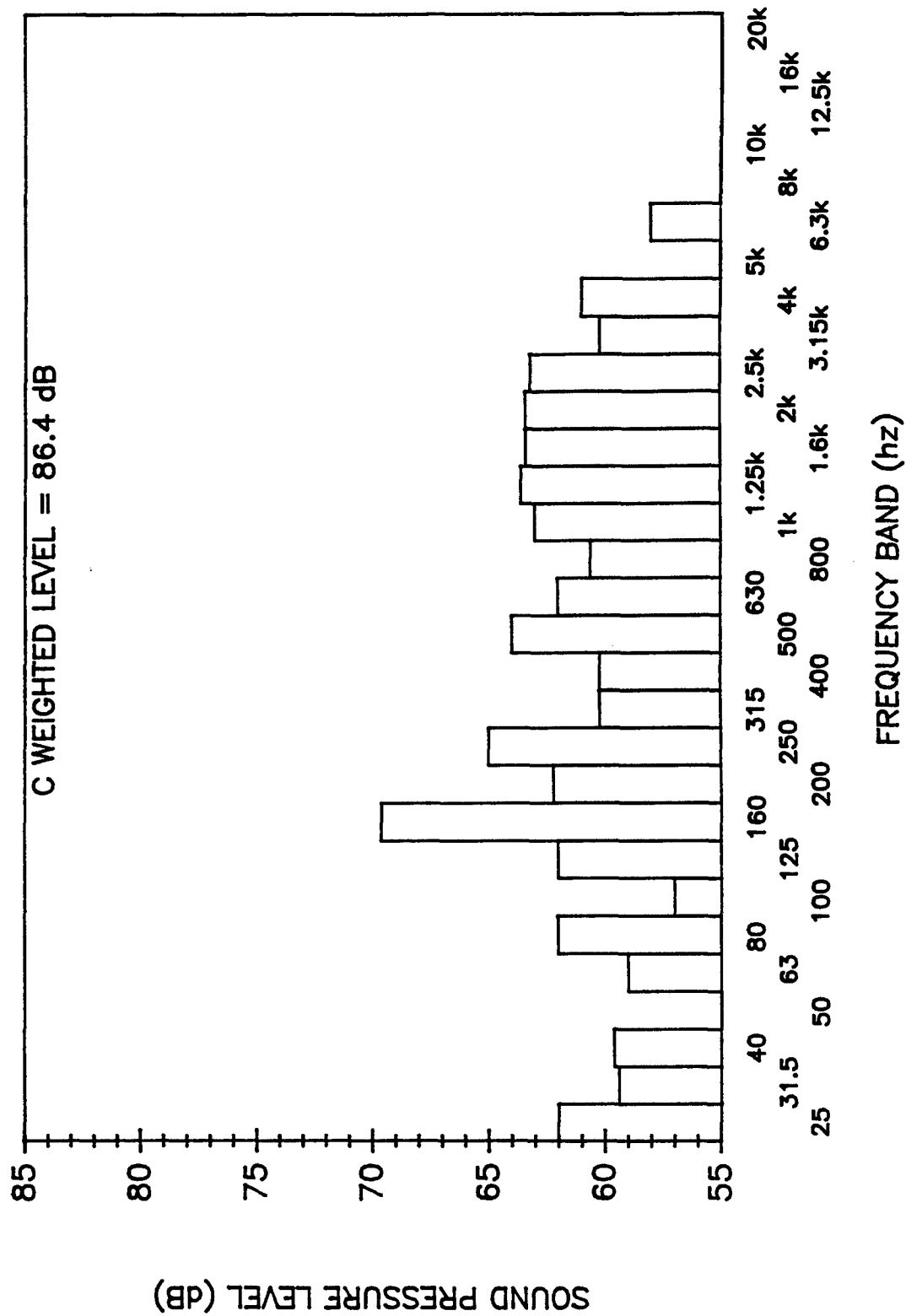
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SMALL SILENCER - 10 MPH PASS-BY - 1 METER FROM LEFT  
MARCH 18, 1991



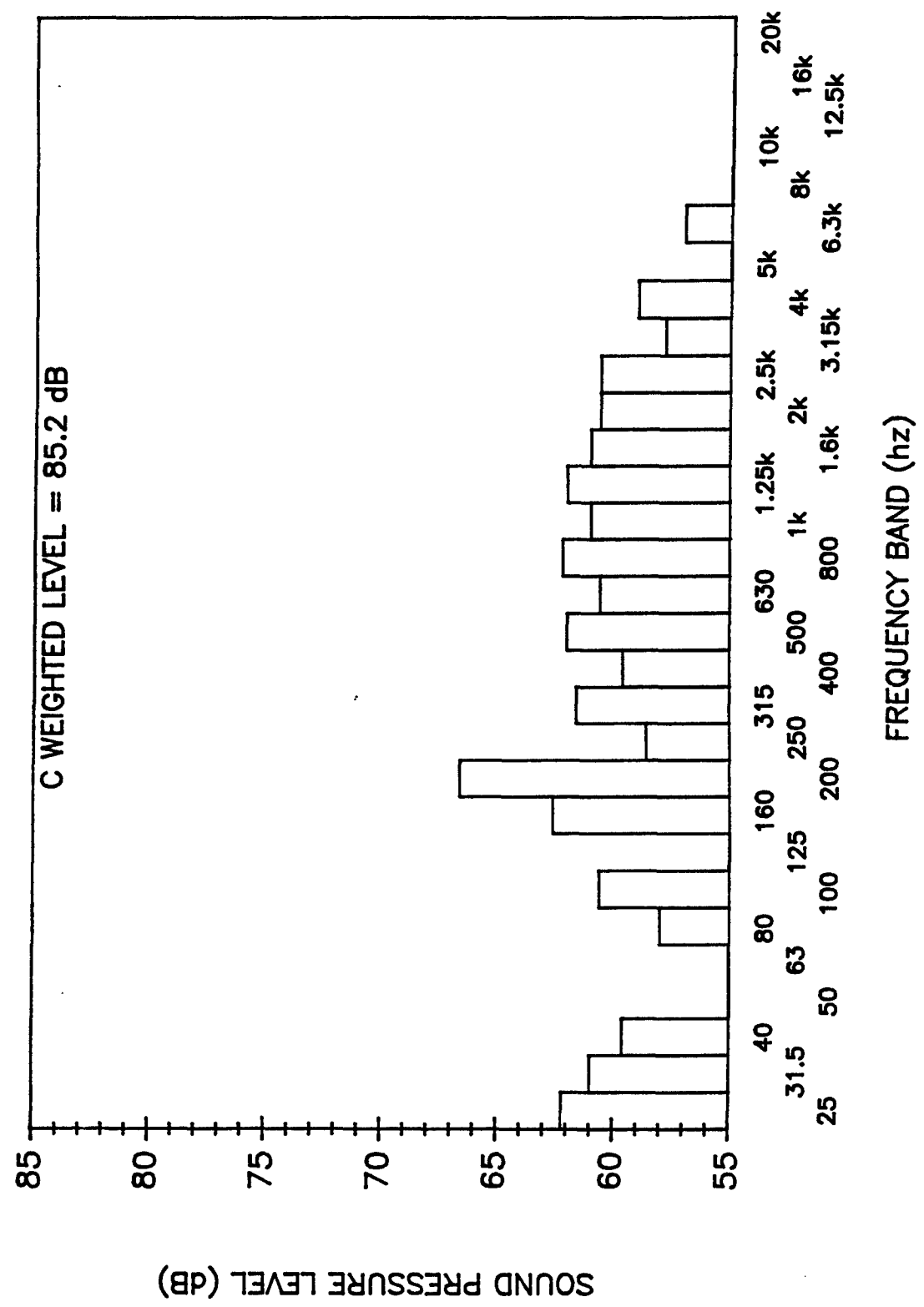
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 SMALL SILENCER - 10 MPH PASS-BY - 1 METER FROM RIGHT  
 MARCH 18, 1991



YAMAHA ET400TRN SOUND PRESSURE LEVEL  
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 MARCH 18, 1991

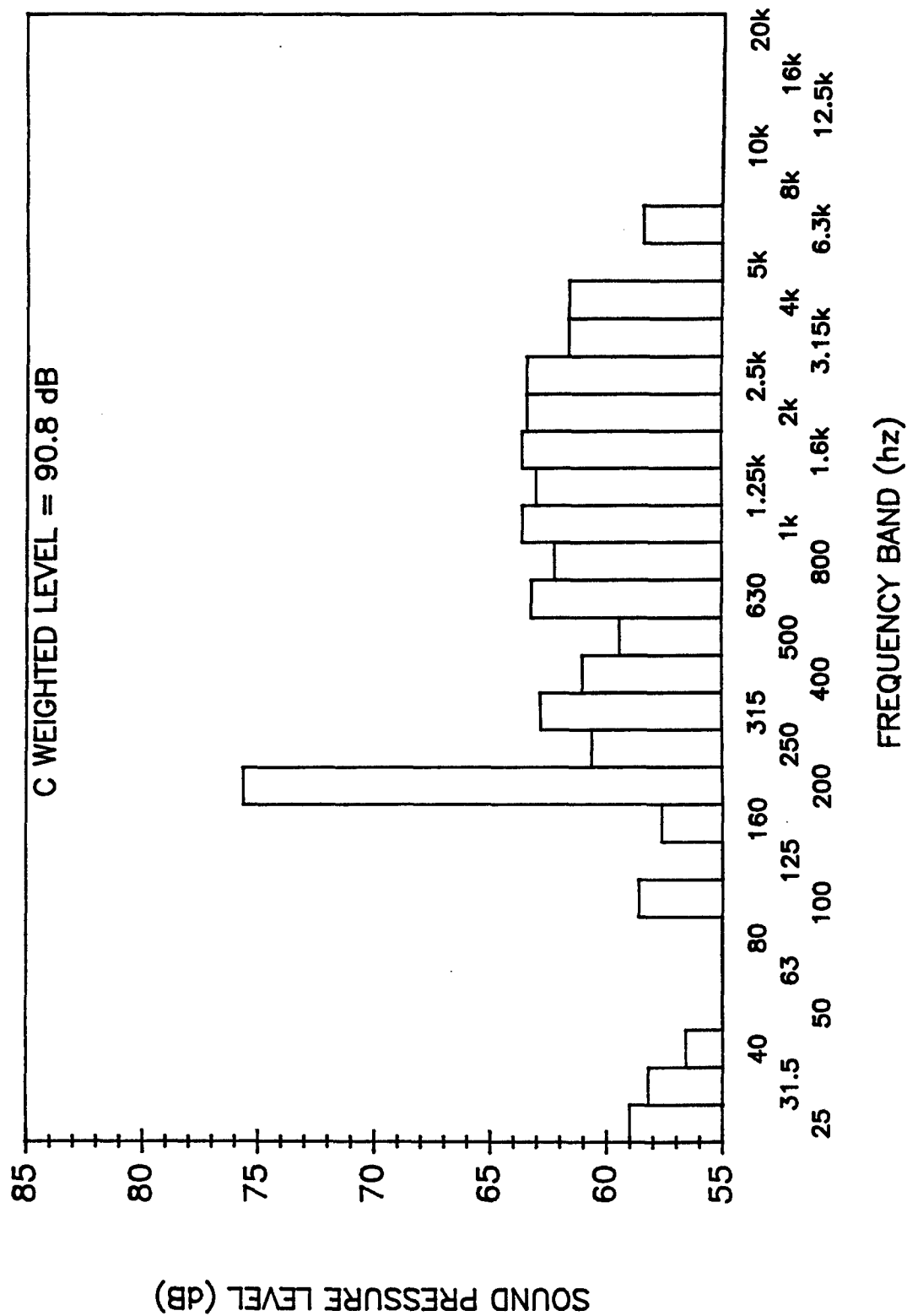


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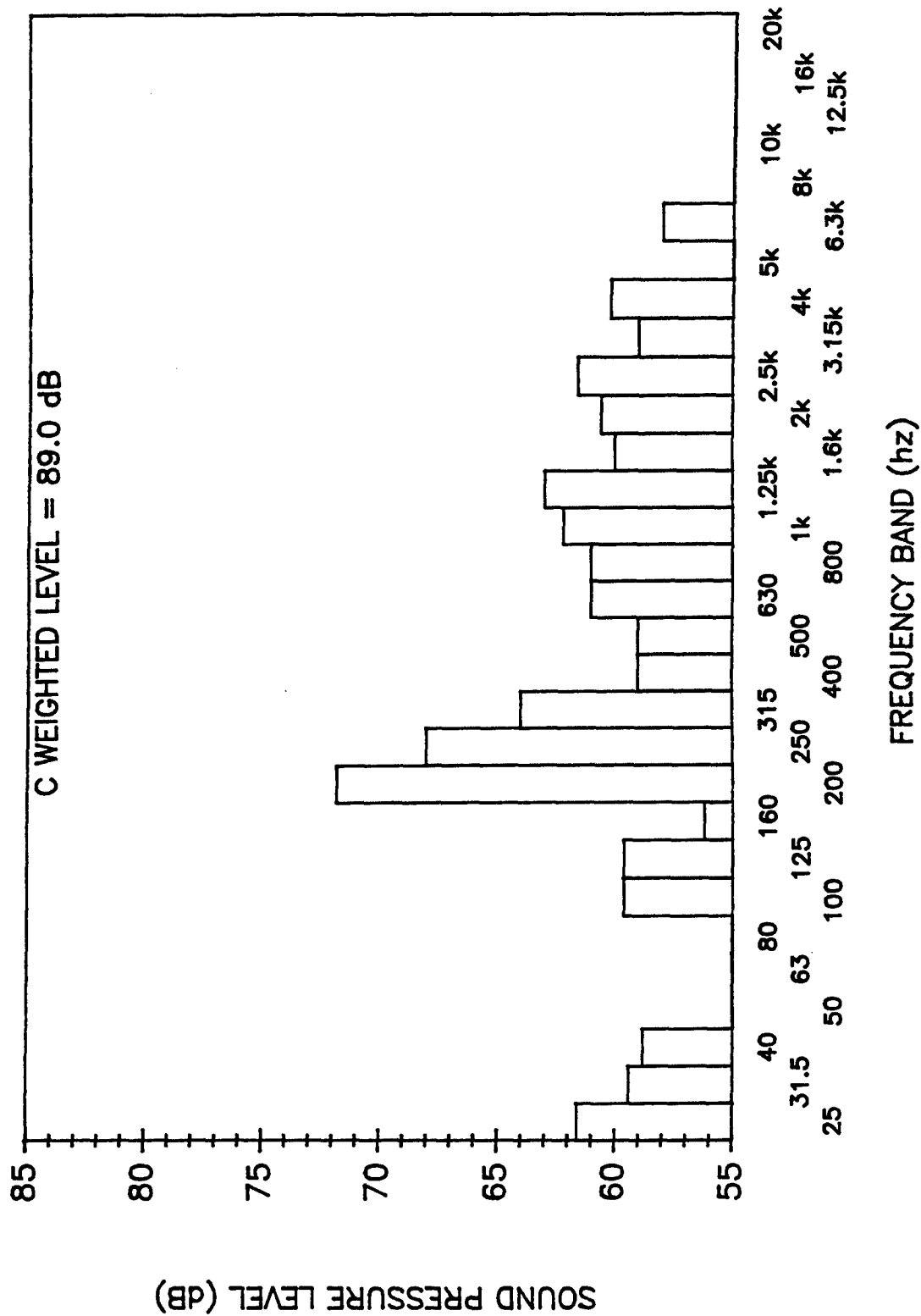




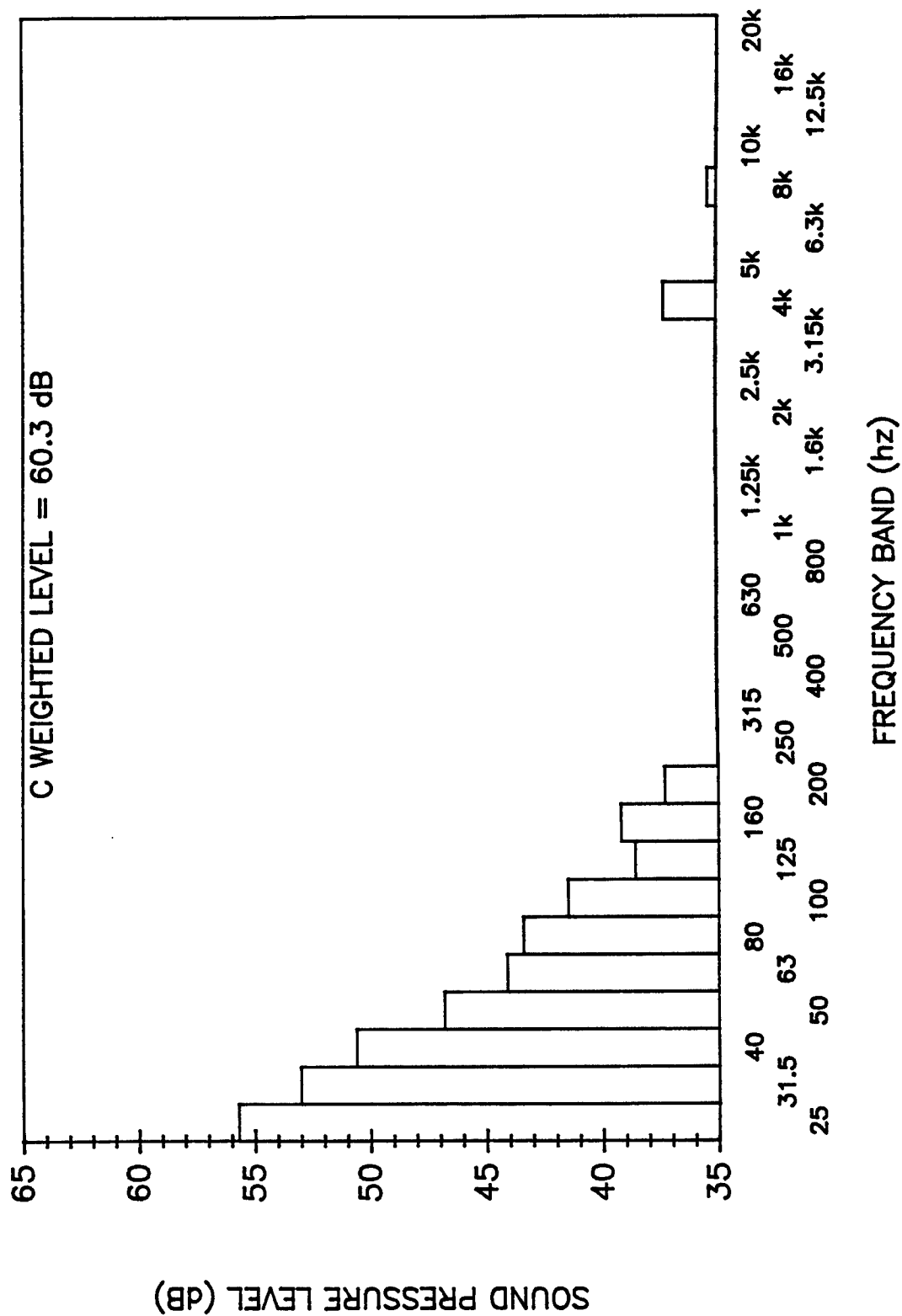
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SMALL SILENCER - 30 MPH PASS-BY - 1 METER FROM LEFT  
MARCH 18, 1991



YAMAHA ET400TRN SOUND PRESSURE LEVEL  
THIRD OCTAVE ANALYSIS - SLOW TIME CONSTANT  
SMALL SILENCER - 30 MPH PASS-BY - 1 METER FROM RIGHT  
MARCH 18, 1991



YAMAHA ET400TRN SOUND PRESSURE LEVEL  
 THIRD OCTAVE ANALYSIS - SLOW TIME CONSTANT  
 AMBIENT POST-TEST AT THE INSTRUMENT 1 METER AWAY  
 MARCH 18, 1991



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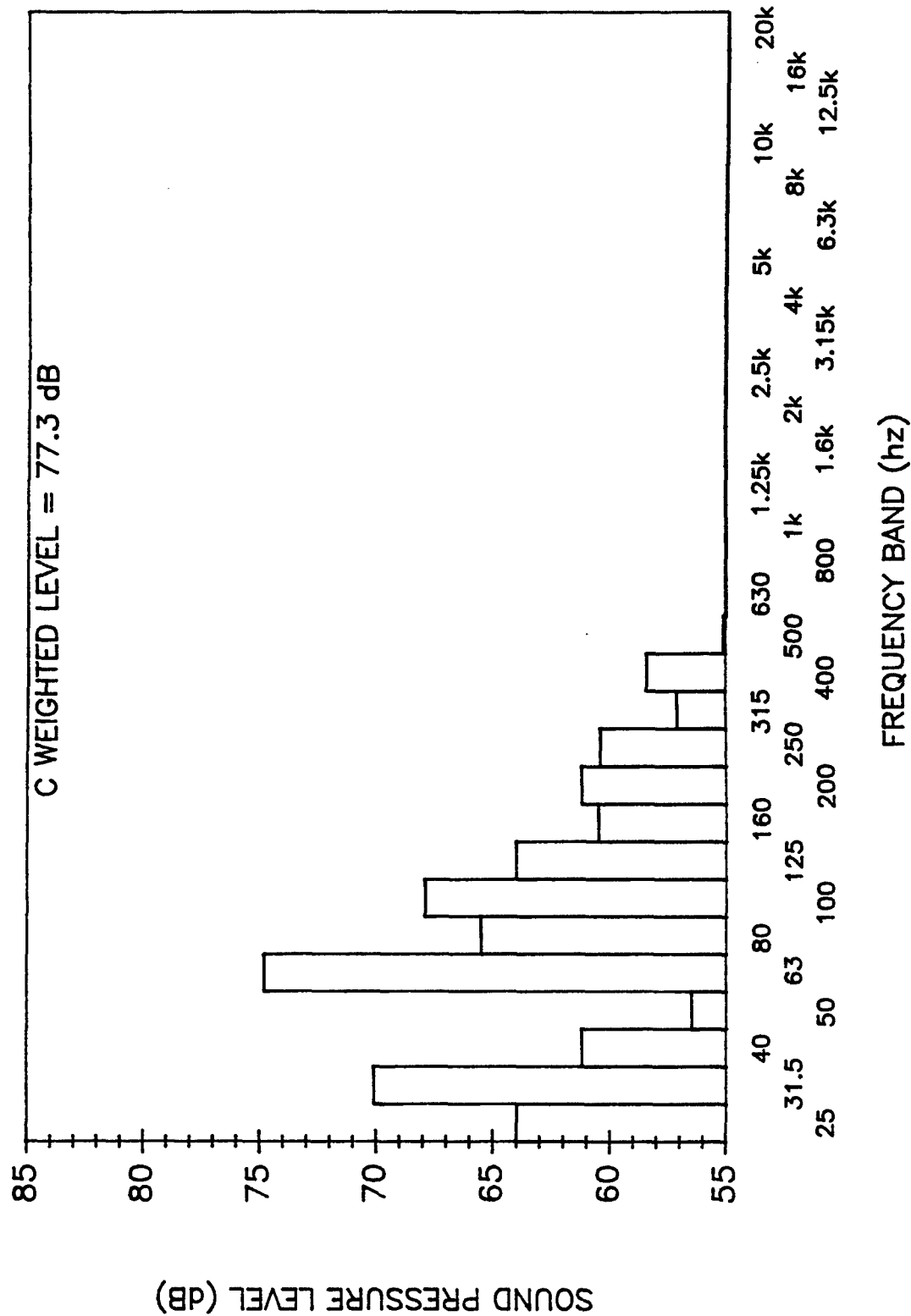
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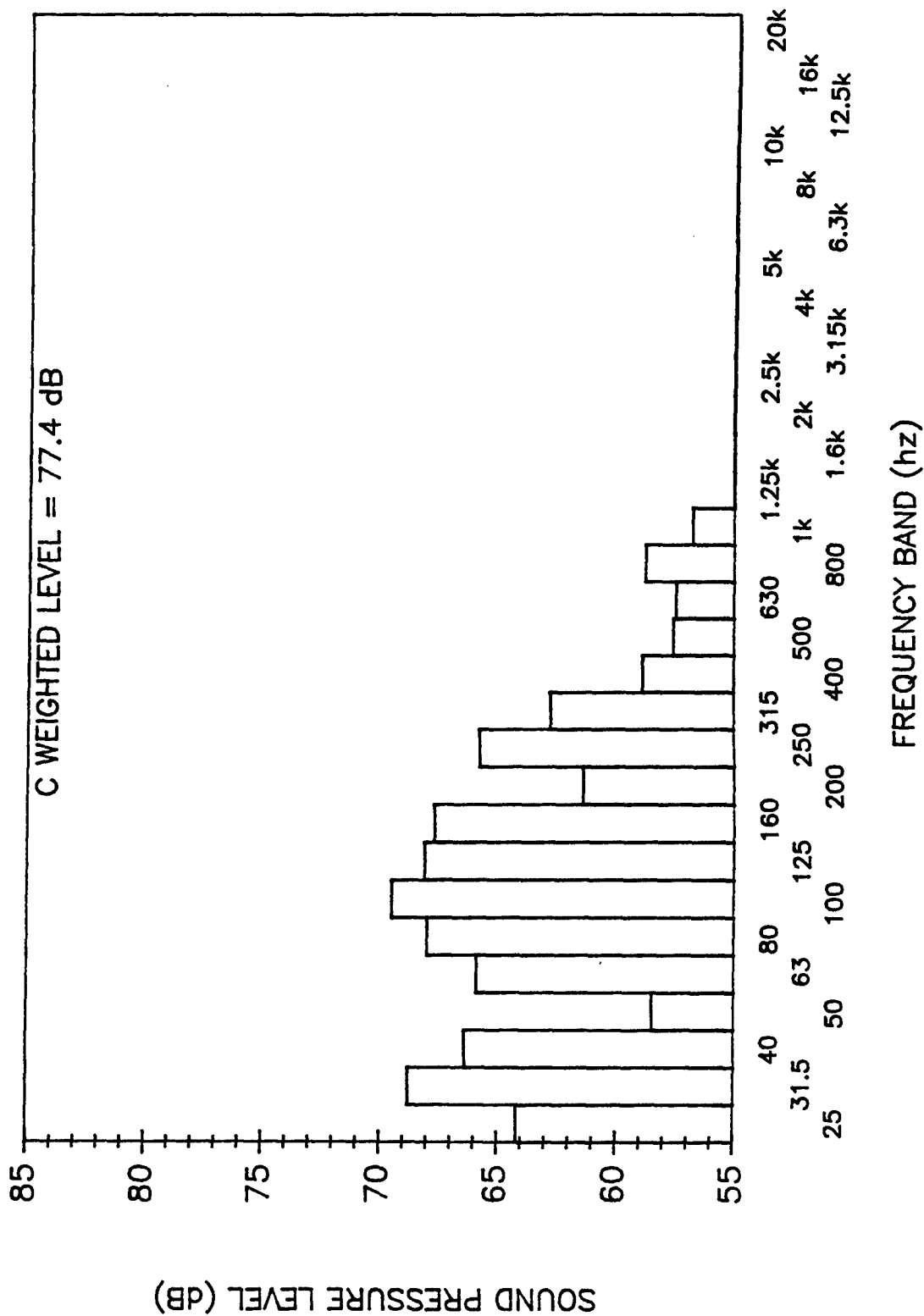
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UCT-2  
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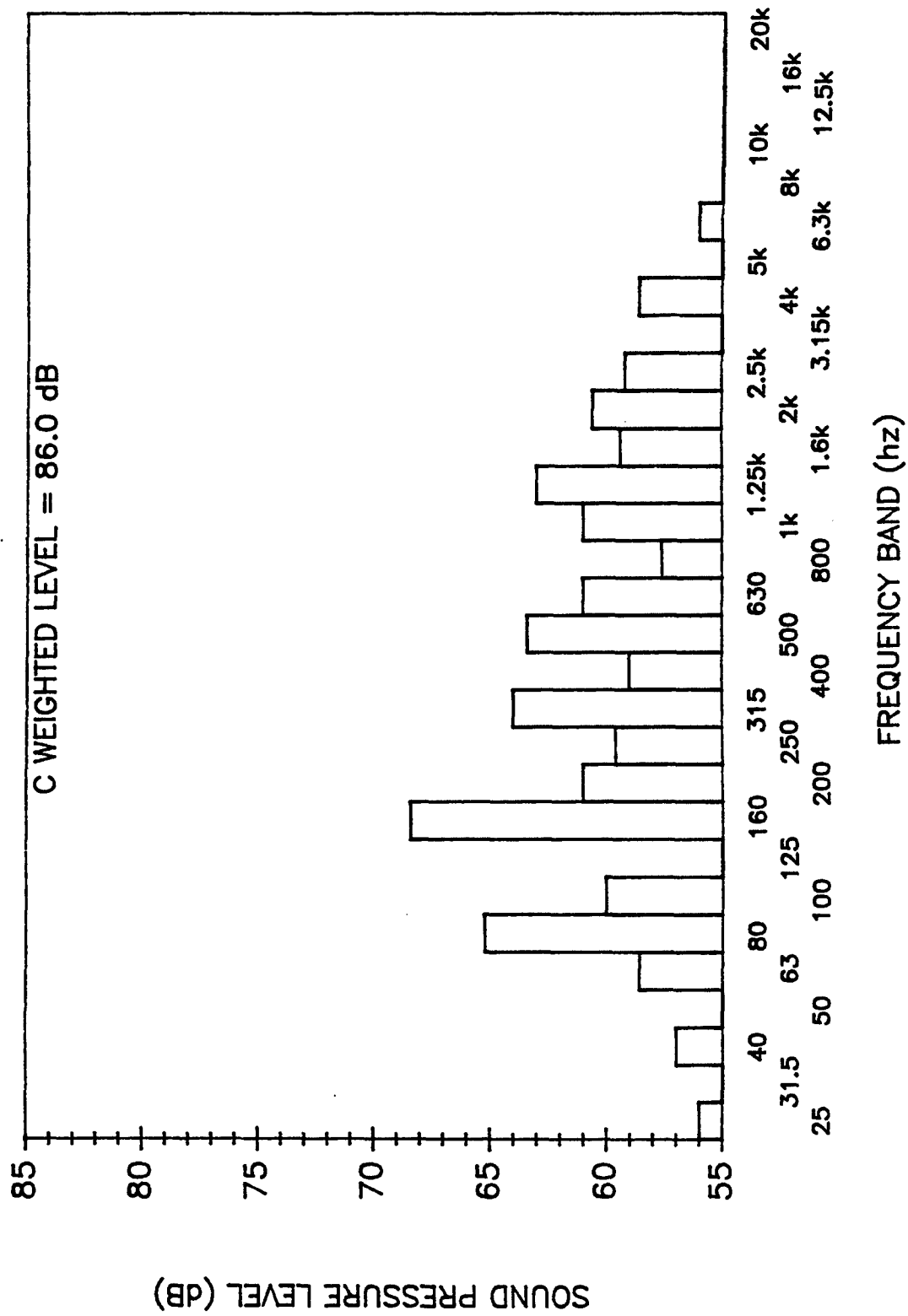
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 THIRD OCTAVE ANALYSIS - SLOW TIME CONSTANT  
 FULL SOUND PACKAGE - IDLING TEST - 1 METER FROM RIGHT  
 MARCH 14, 1991



YAMAHA ET400TRN SOUND PRESSURE LEVEL  
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MARCH 14, 1991

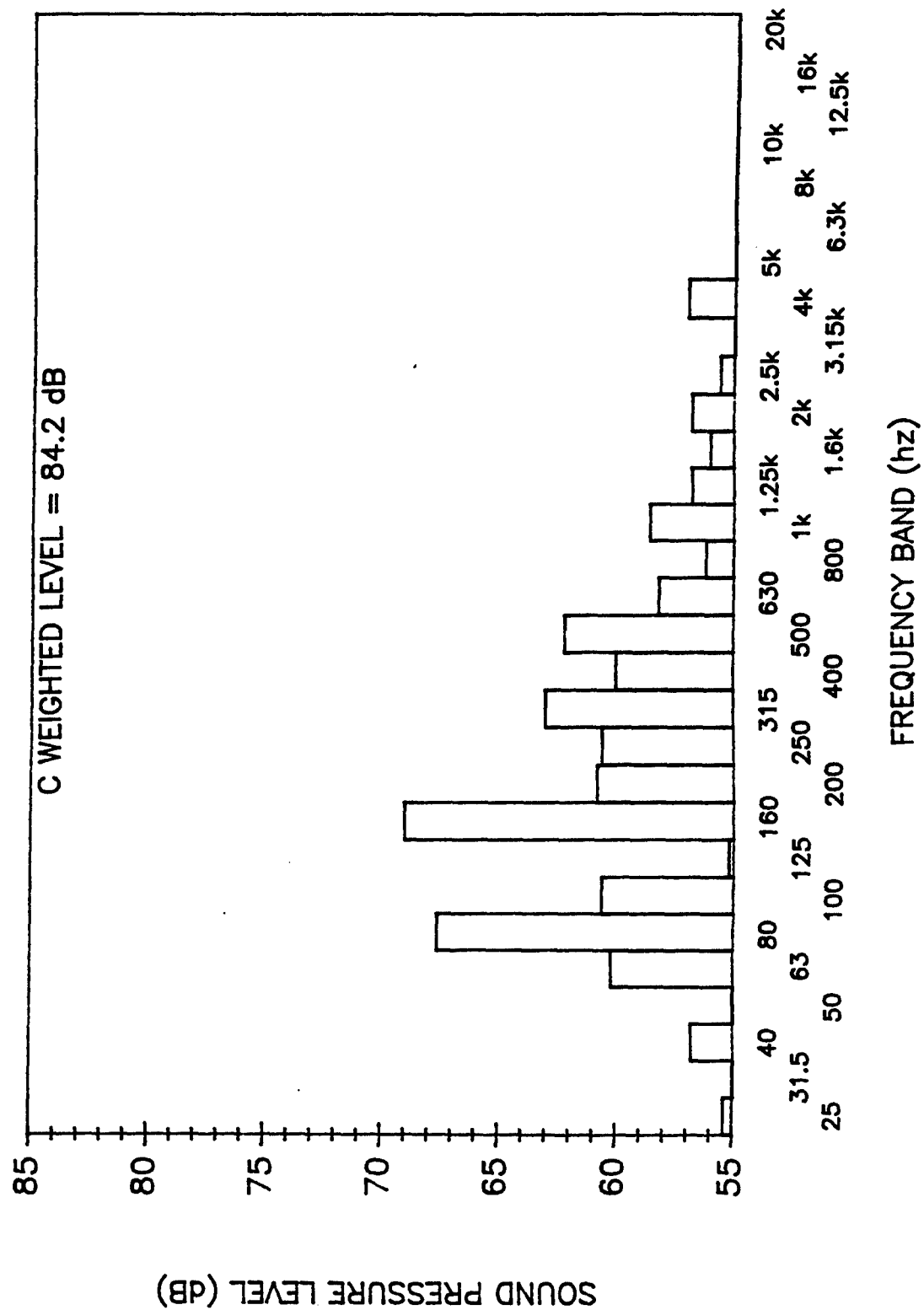


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 FULL SOUND PACKAGE - 10 MPH PASS-BY - 1 METER FROM LEFT  
 MARCH 14, 1991

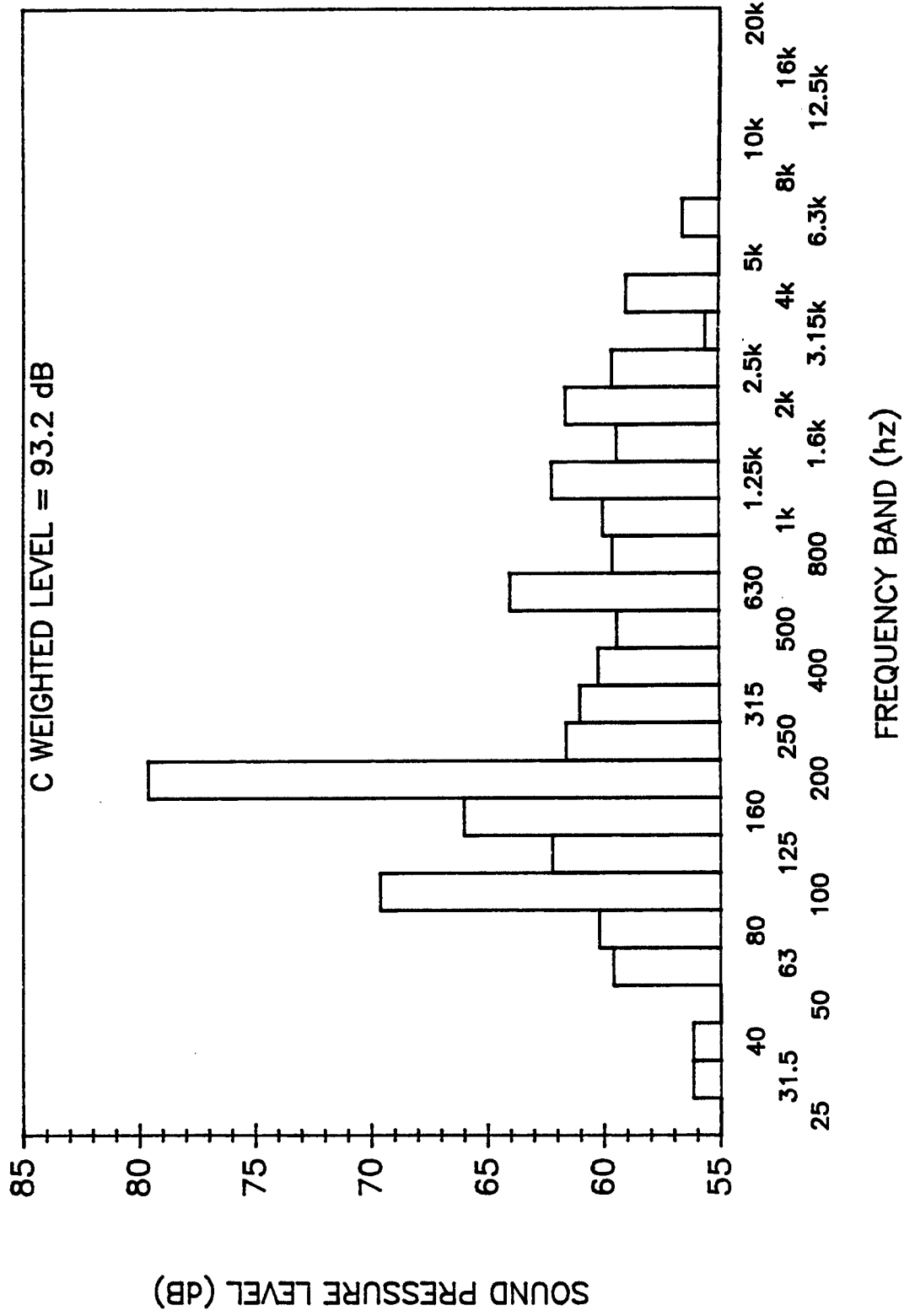




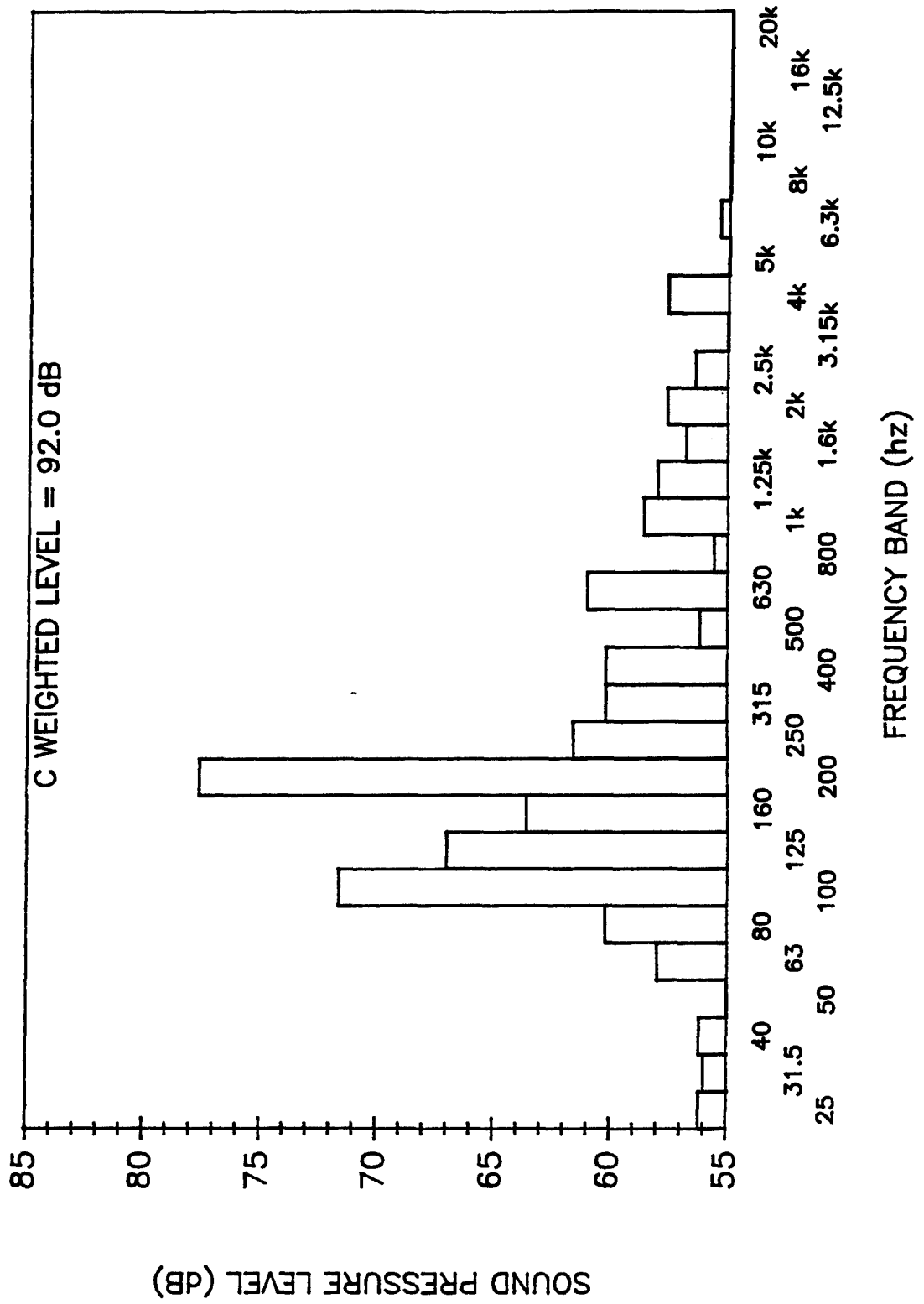
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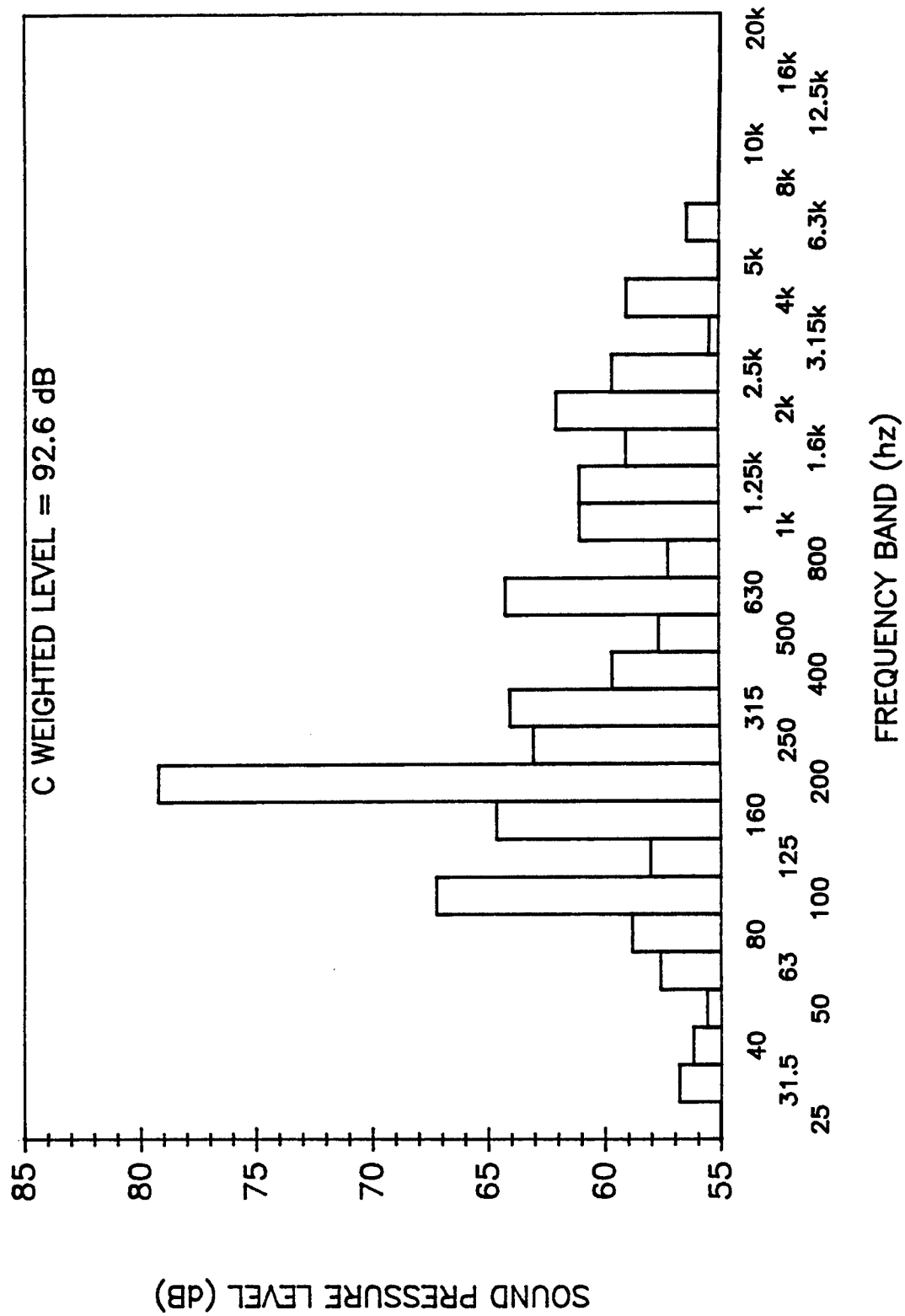
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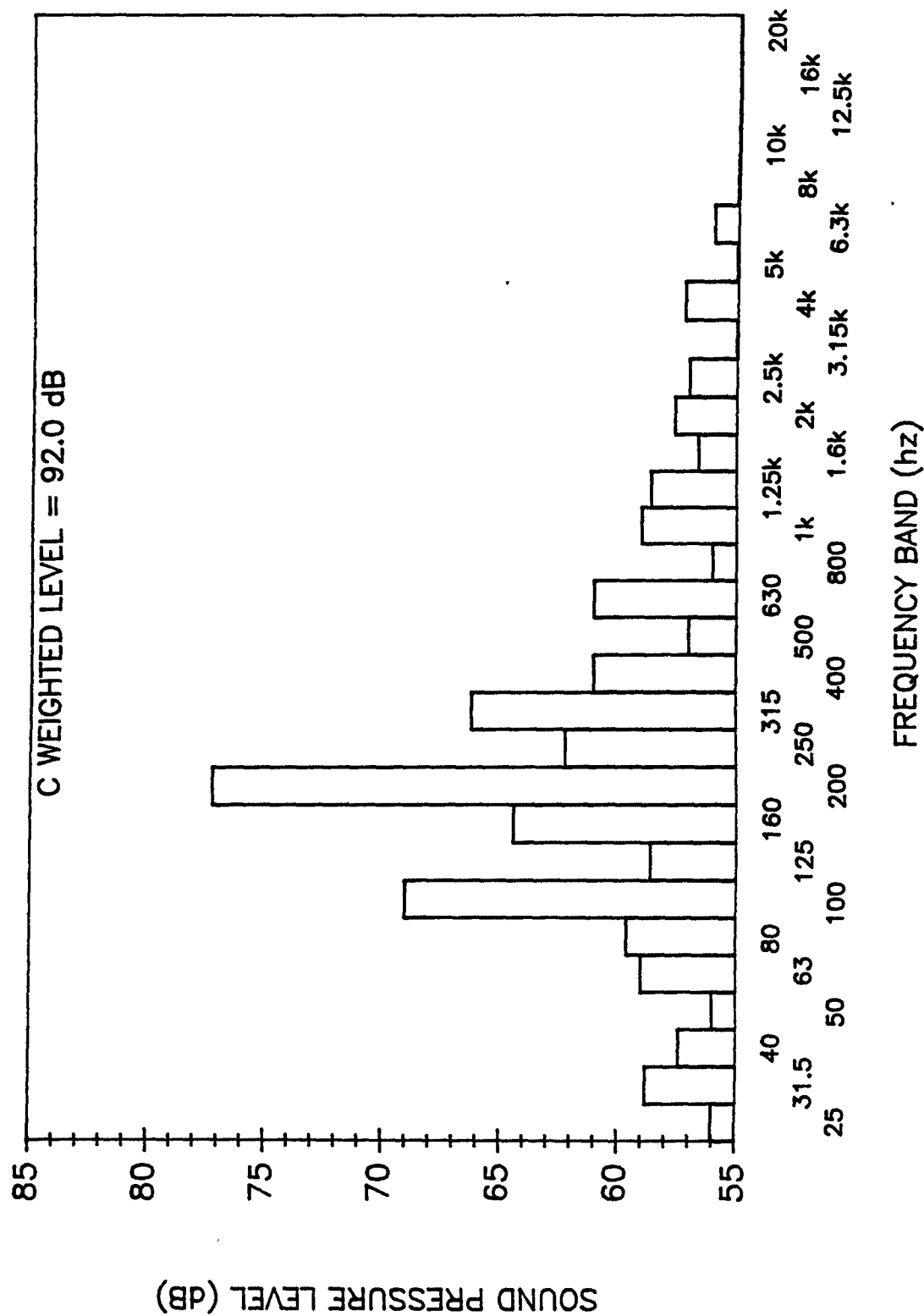
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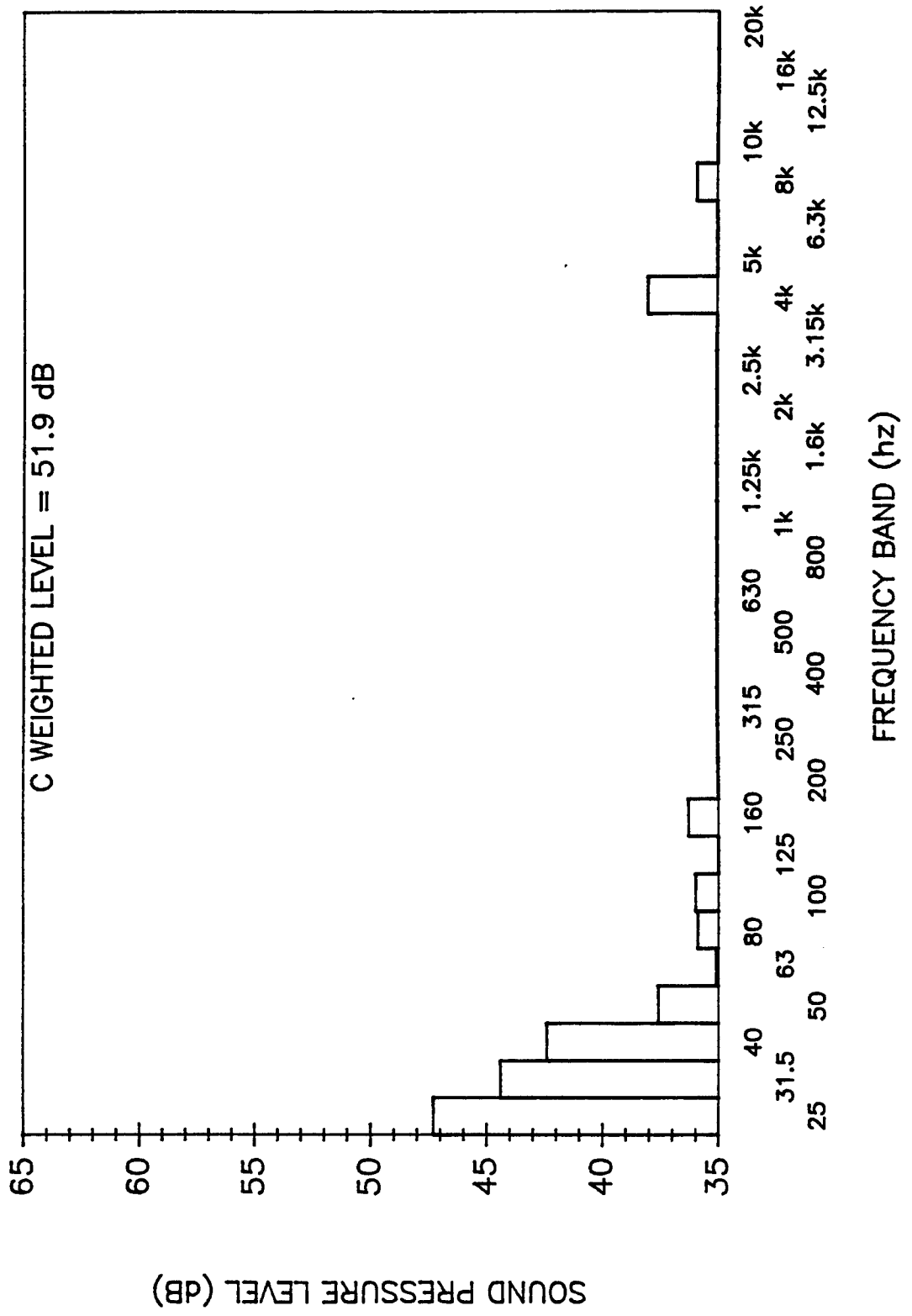
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 FULL SOUND PACKAGE - 30 MPH PASS-BY - 1 METER FROM LEFT  
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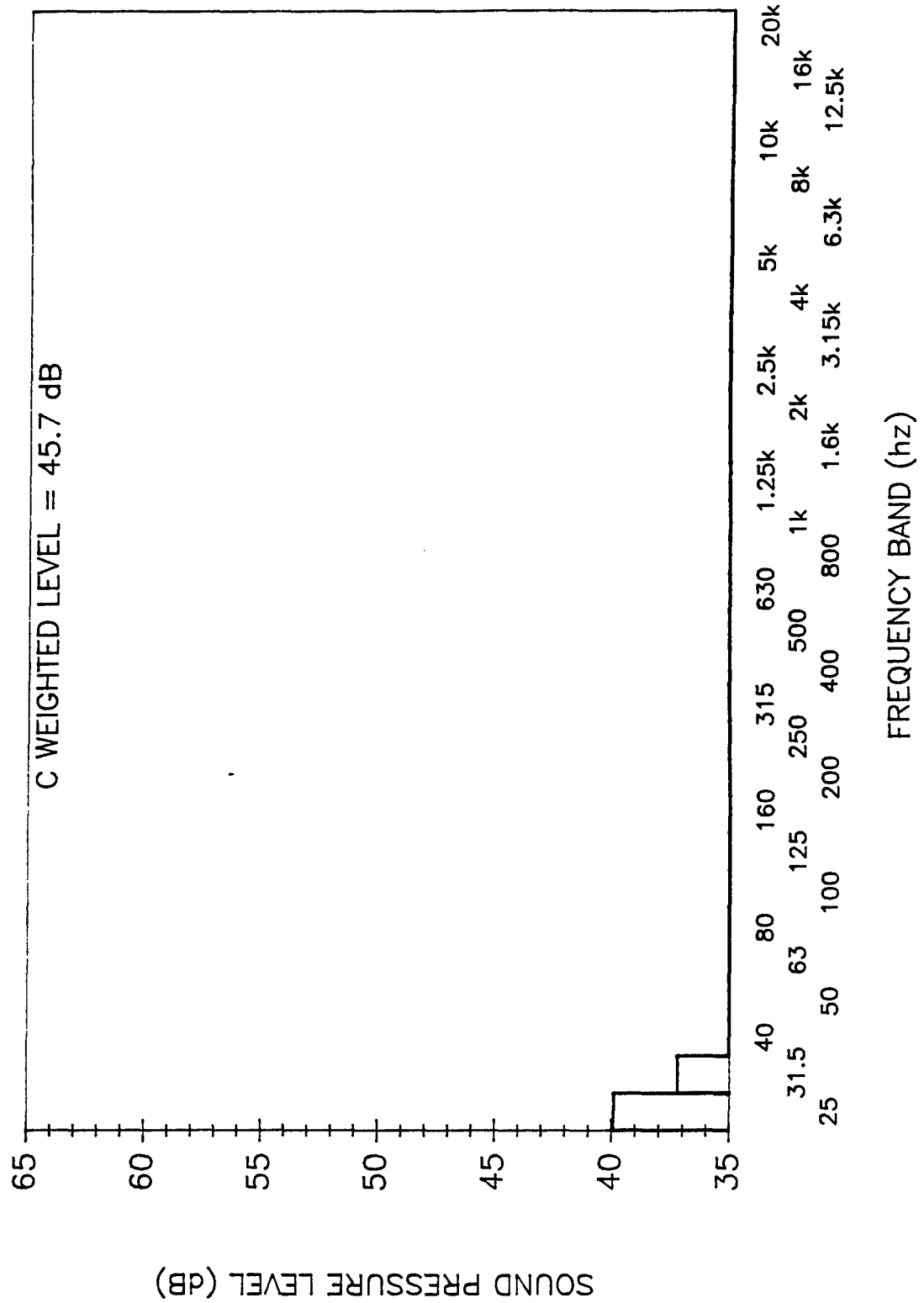
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FULL SOUND PACKAGE - 30 MPH PASS-BY - 1 METER FROM RIGHT  
MARCH 14, 1991



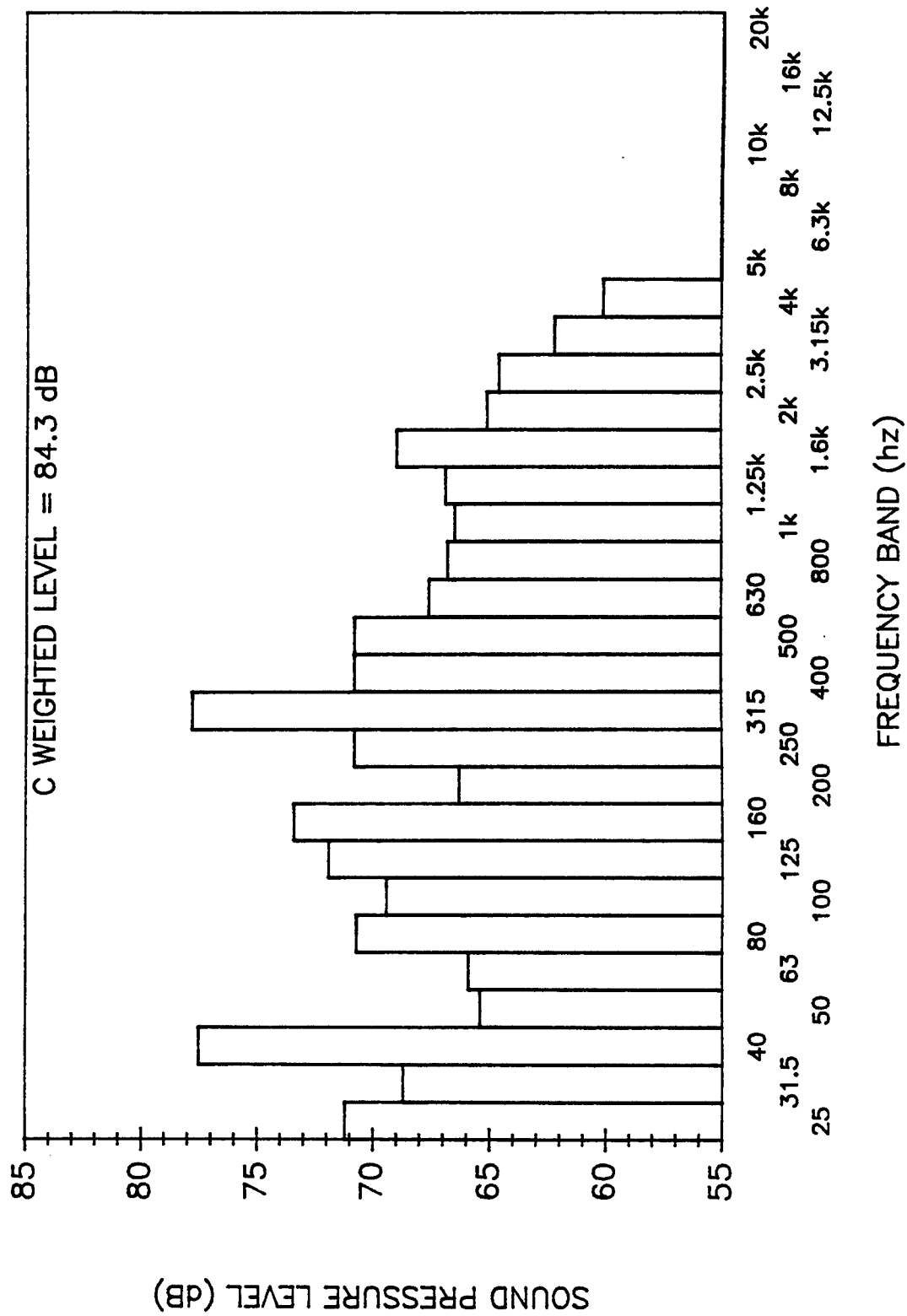
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AMBIENT POST-TEST AT THE INSTRUMENT 1 METER AWAY  
MARCH 14, 1991



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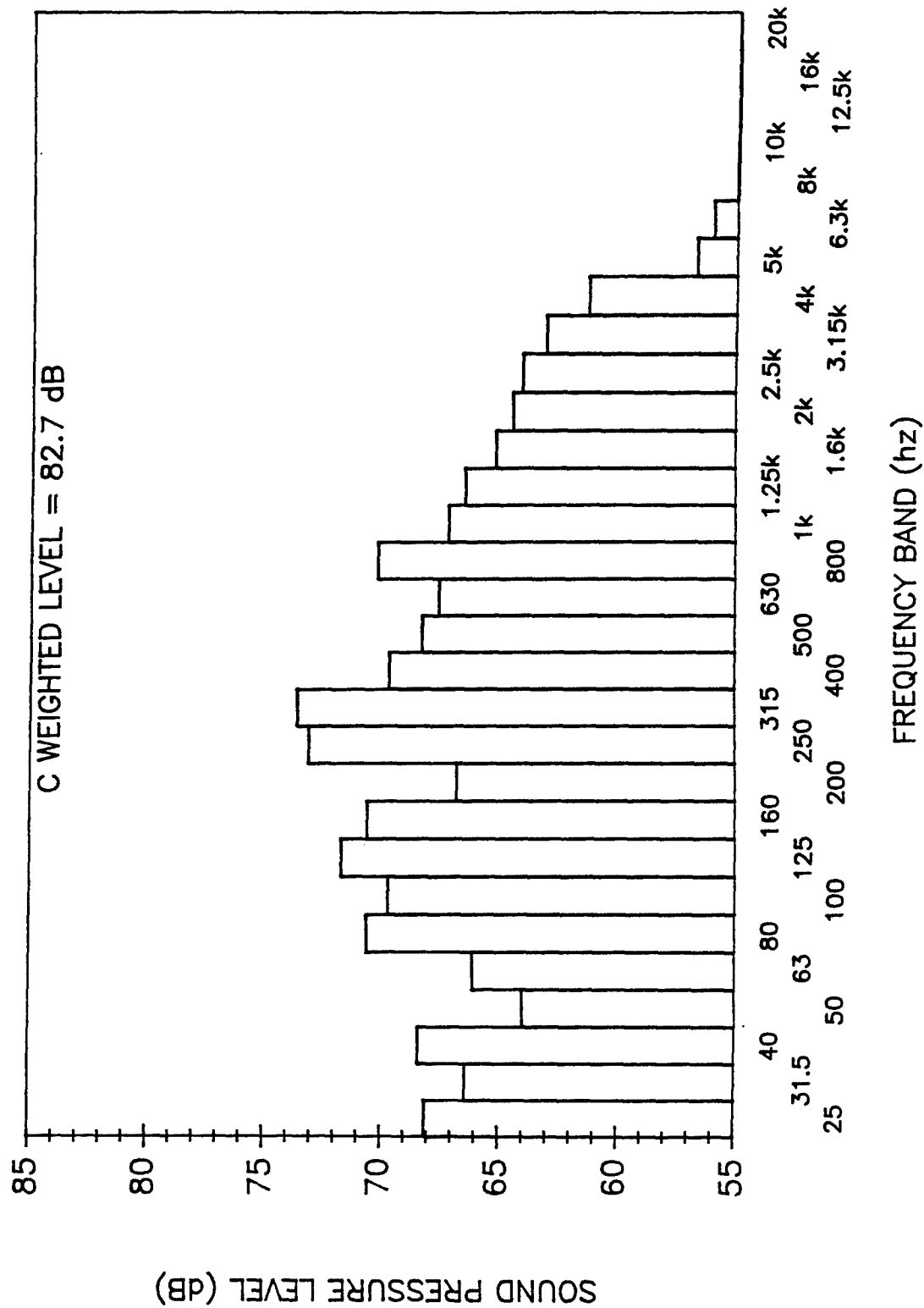


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SKIRT - IDLING TEST - 1 METER FROM LEFT  
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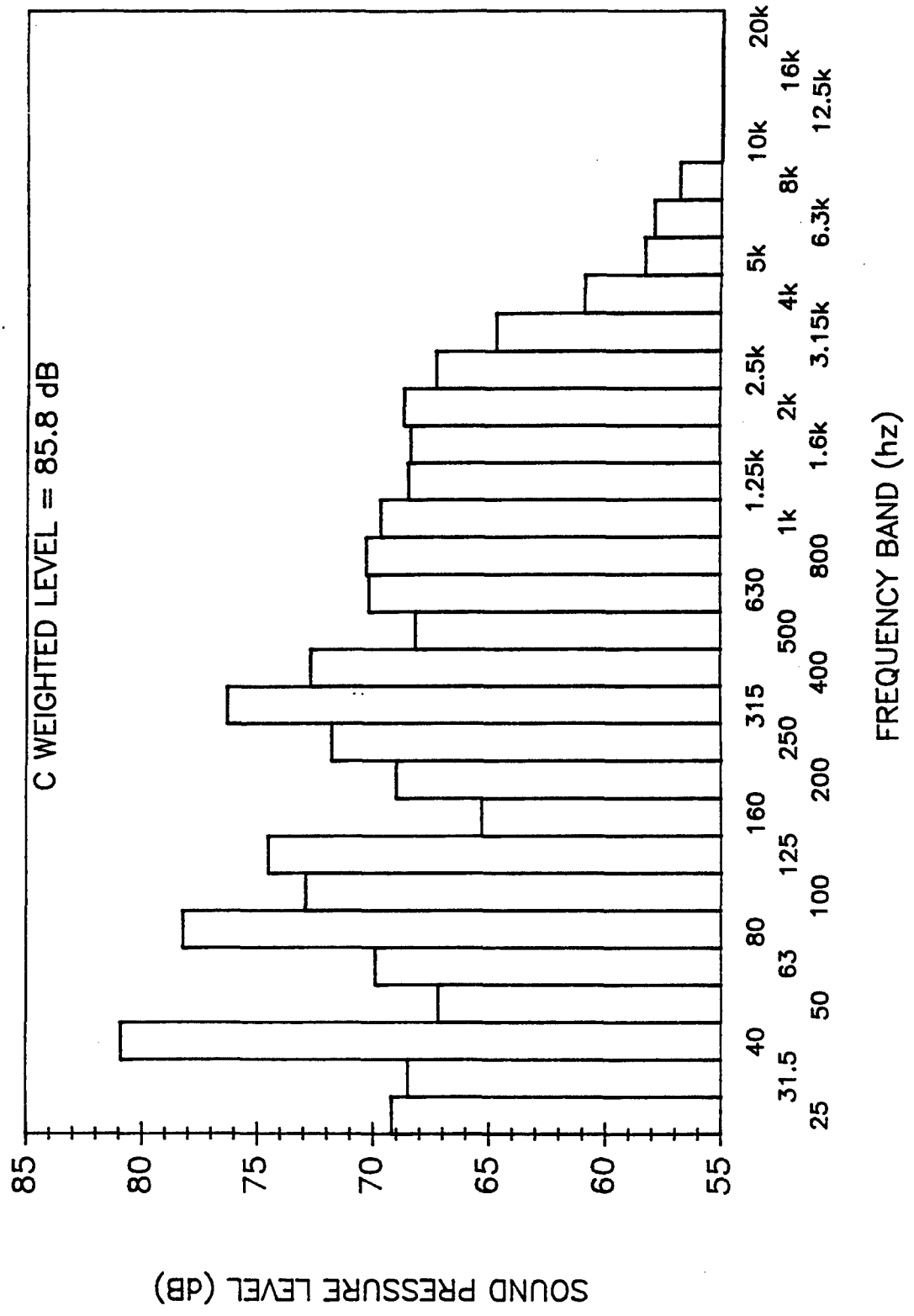




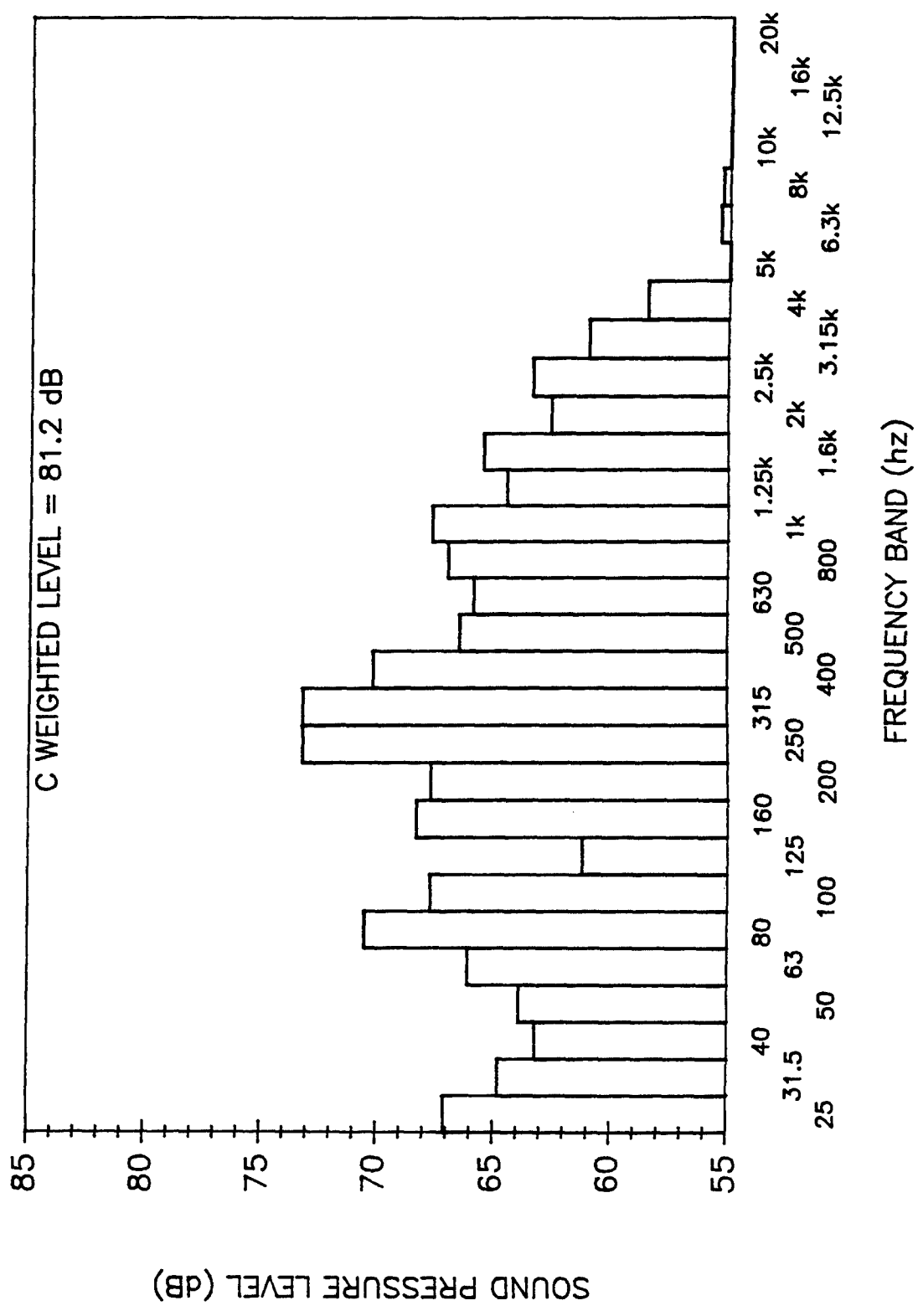
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SKIRT - IDLING TEST - 1 METER FROM FRONT  
MARCH 15, 1991



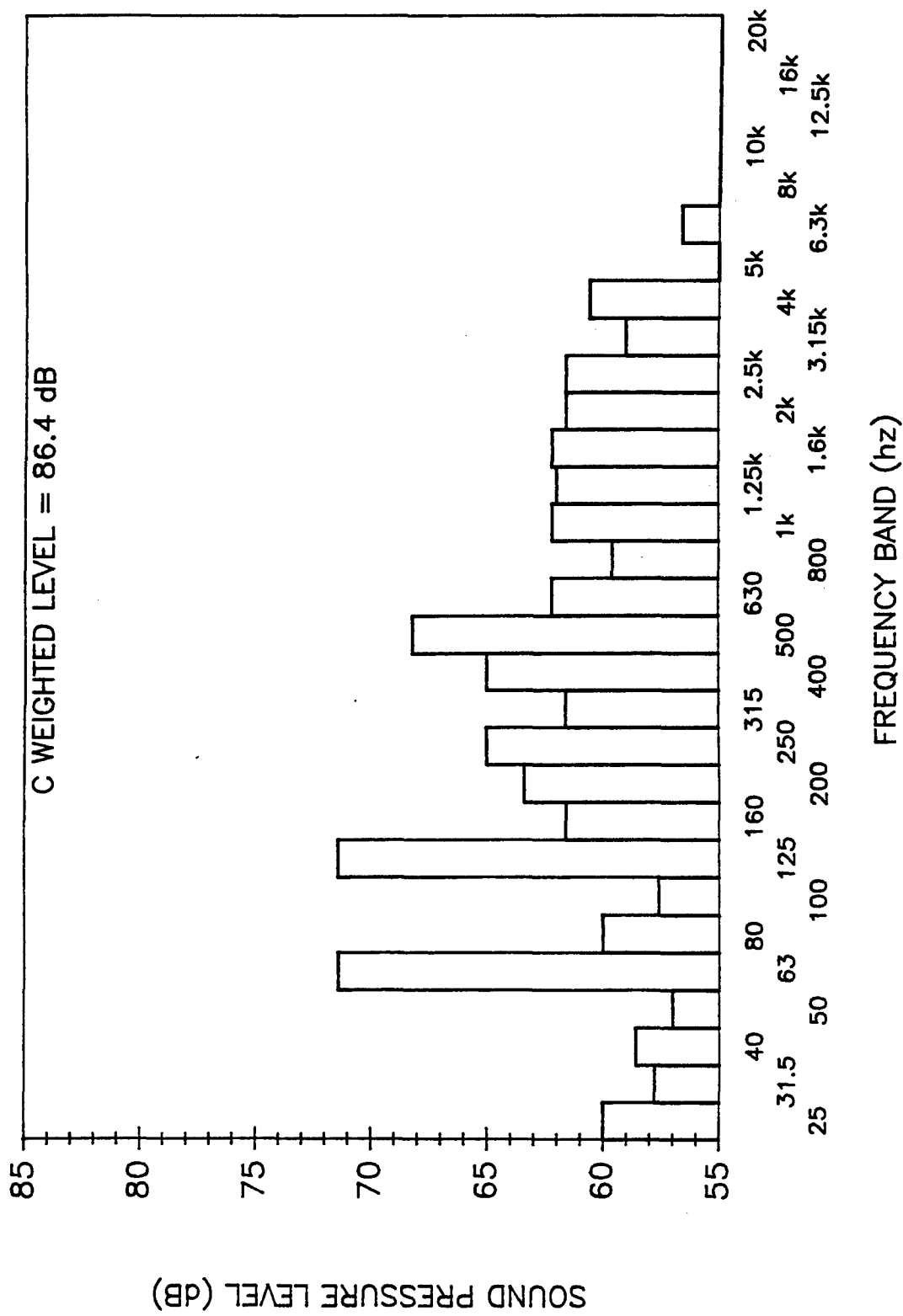
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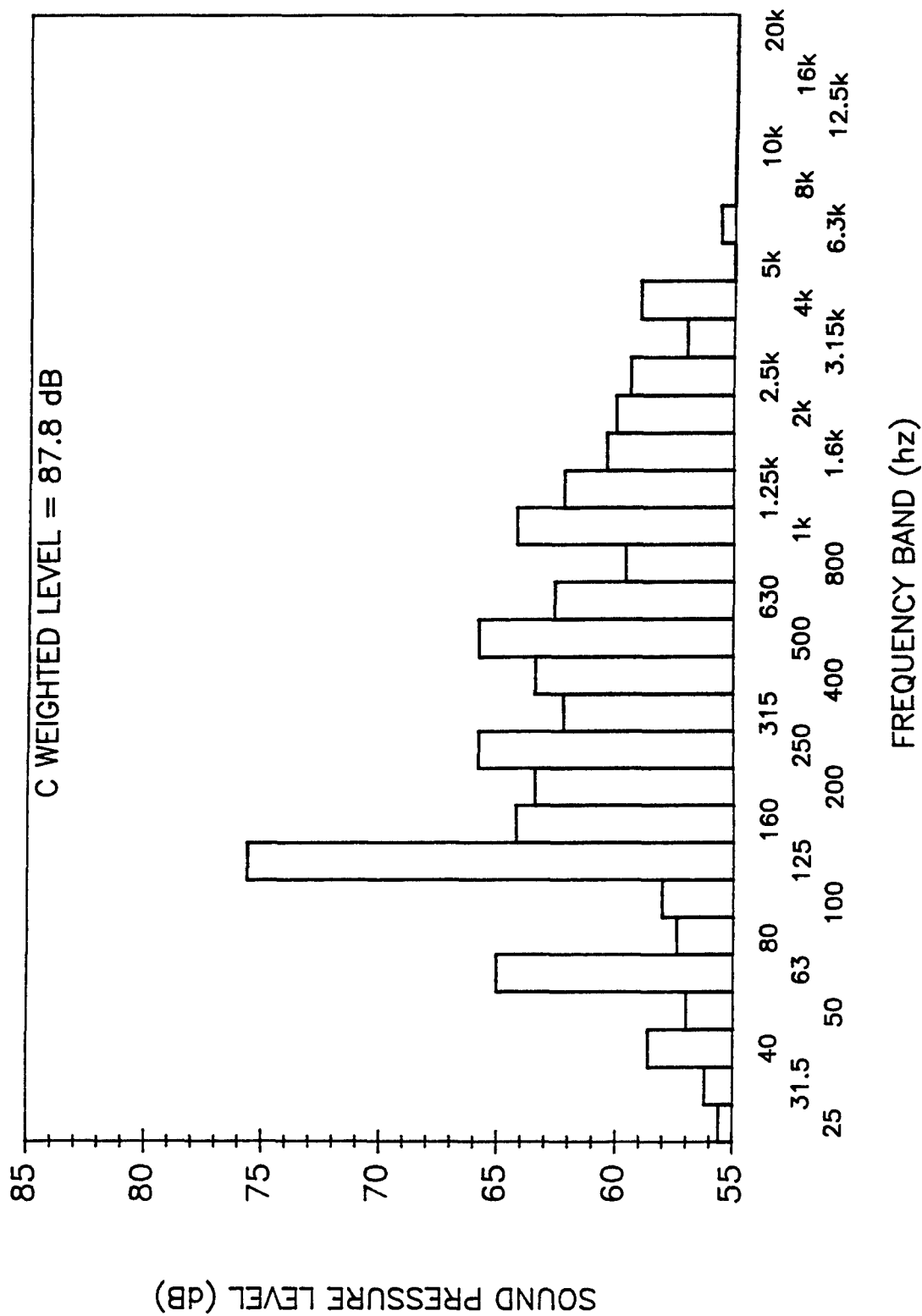
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SKIRT - IDLING TEST - 1 METER FROM REAR  
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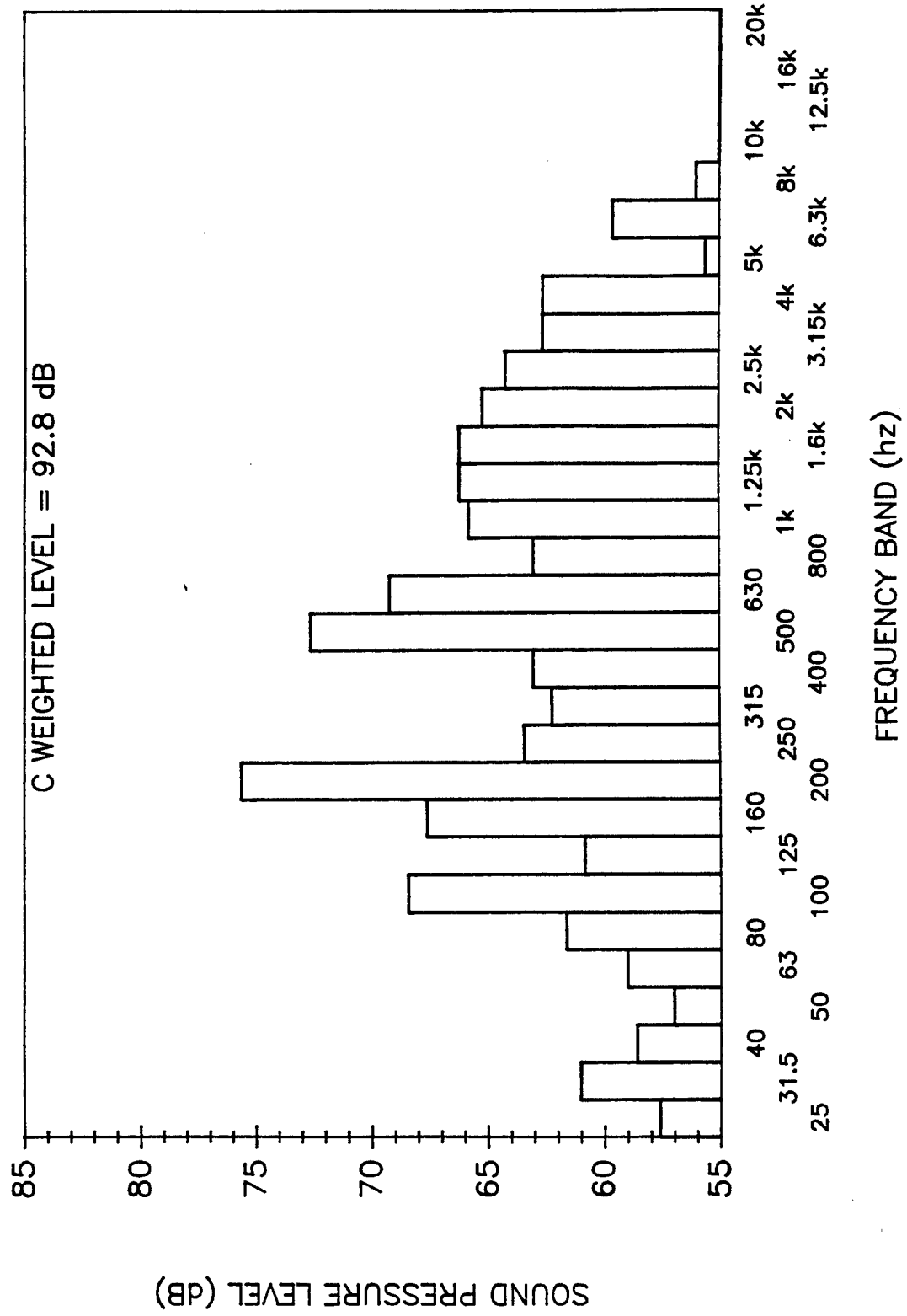
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 SKIRT - 10 MPH PASS-BY - 1 METER FROM LEFT  
 MARCH 15, 1991



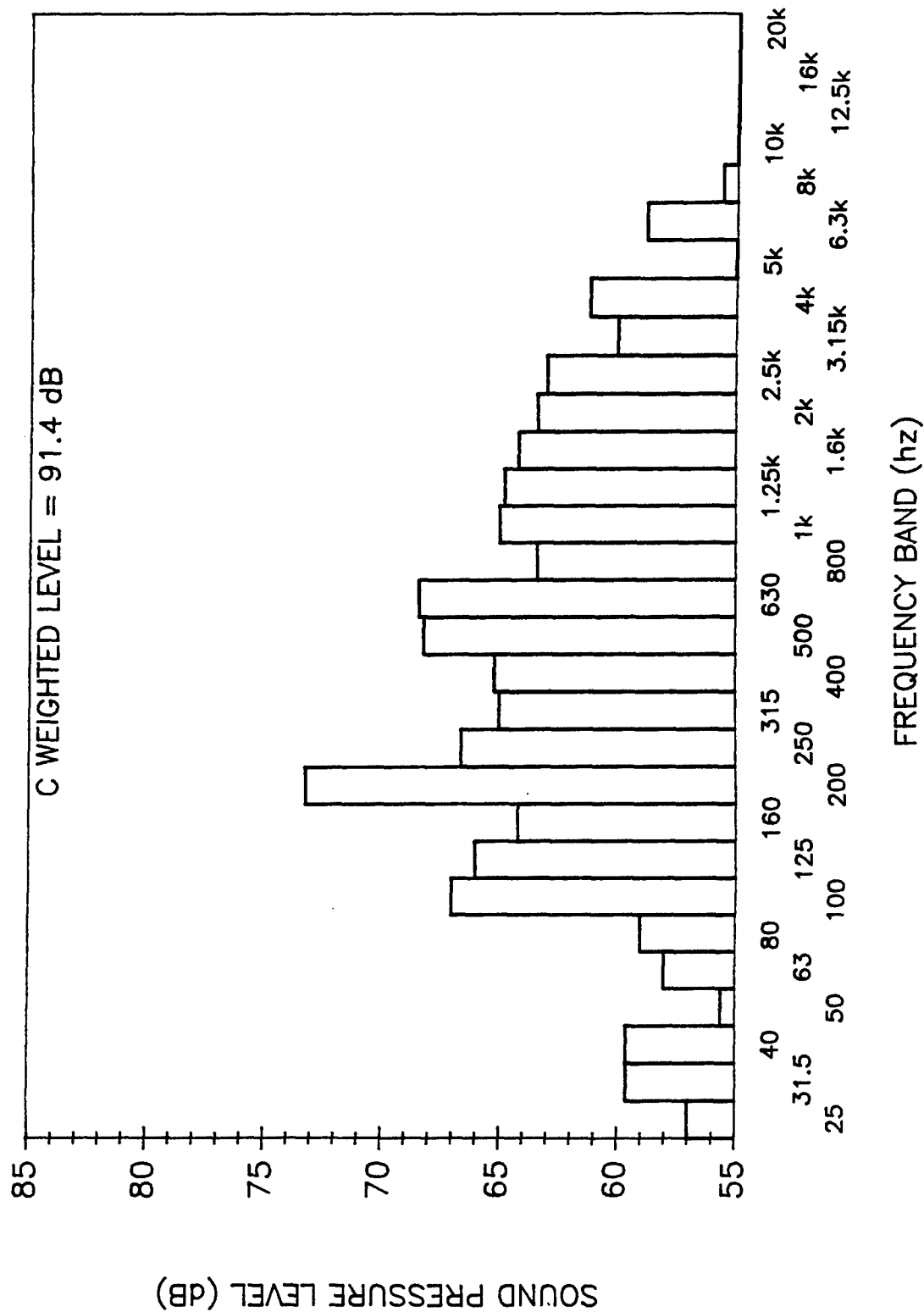
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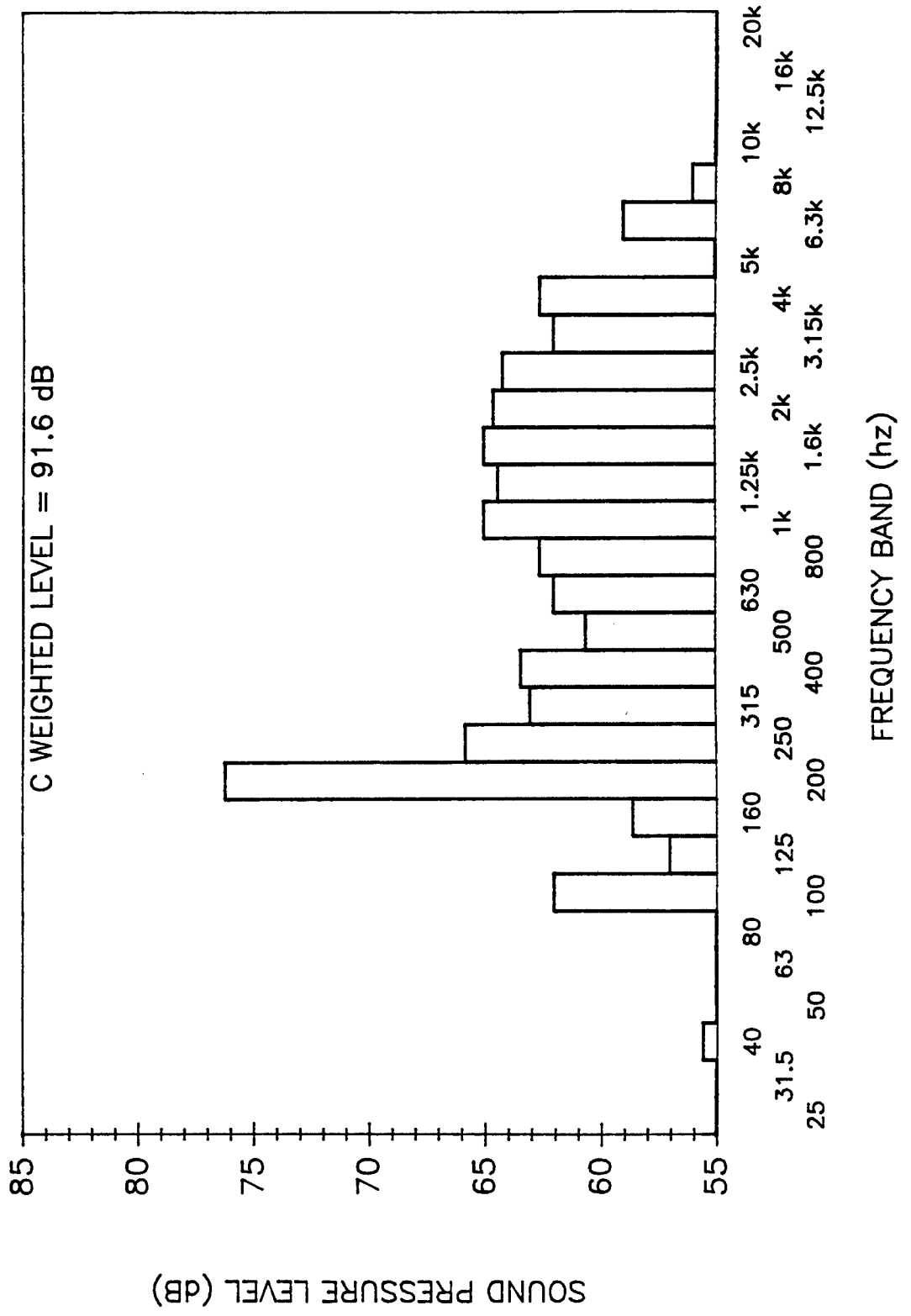
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 SKIRT - 20 MPH PASS-BY - 1 METER FROM LEFT  
 MARCH 15, 1991



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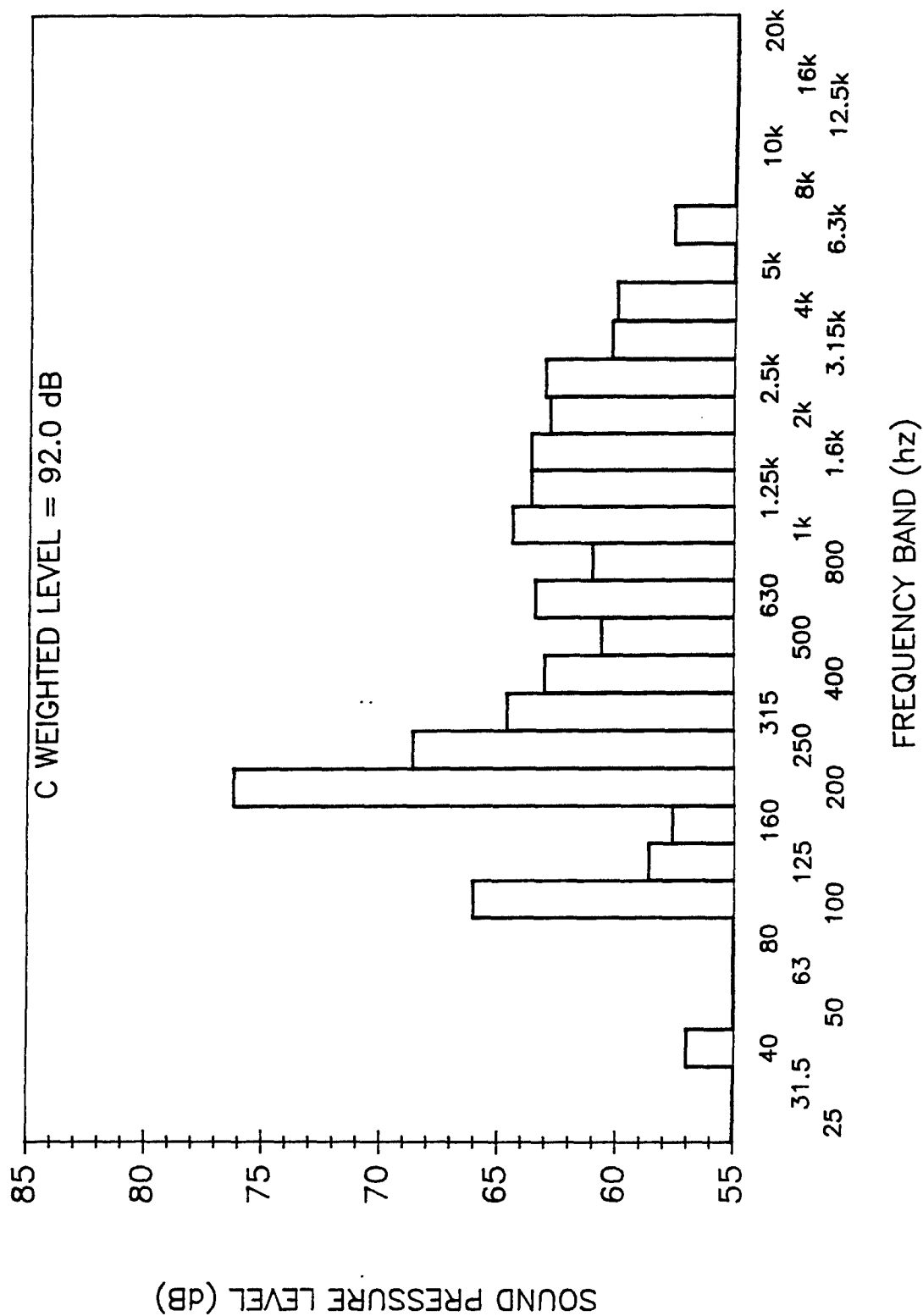


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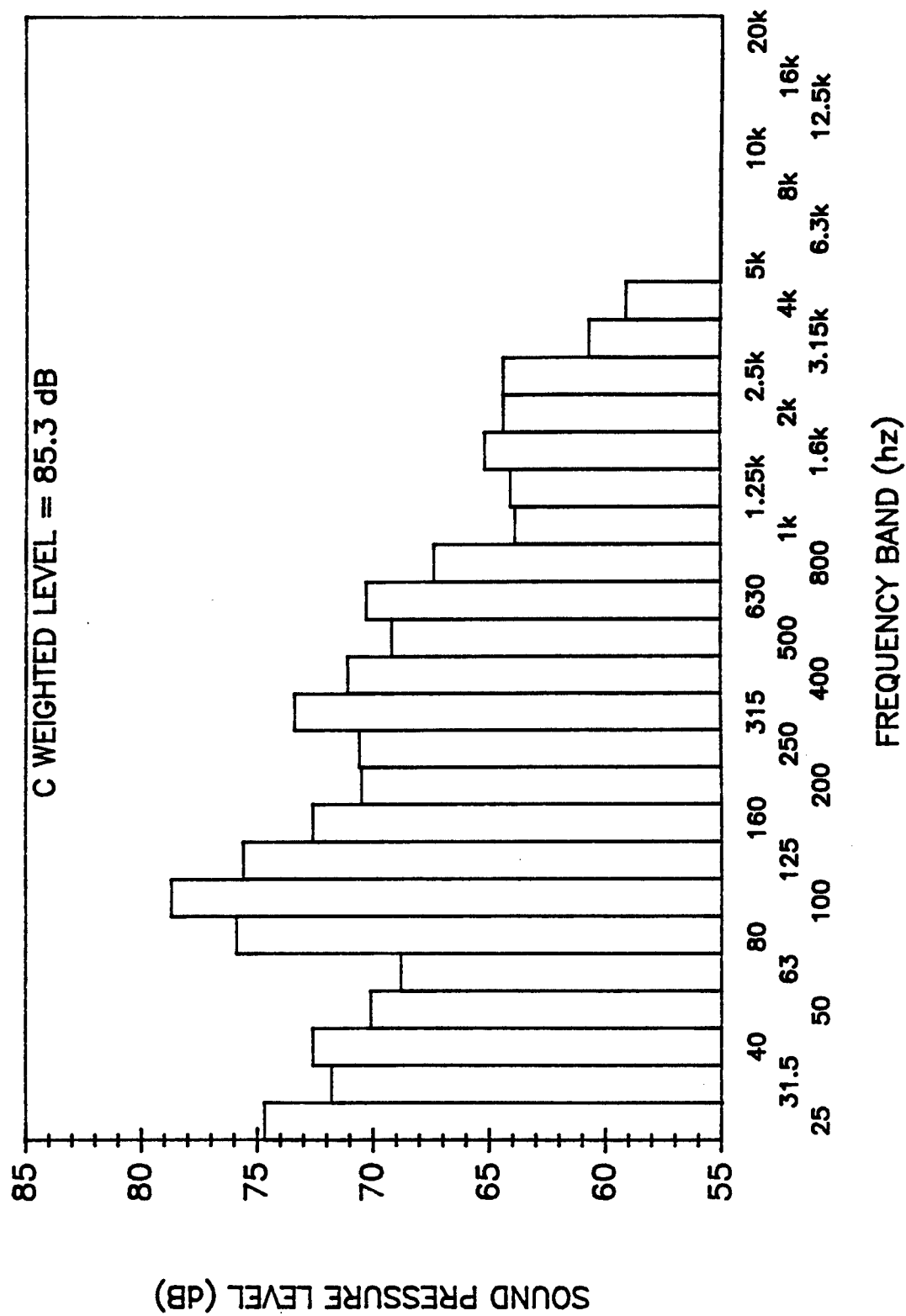




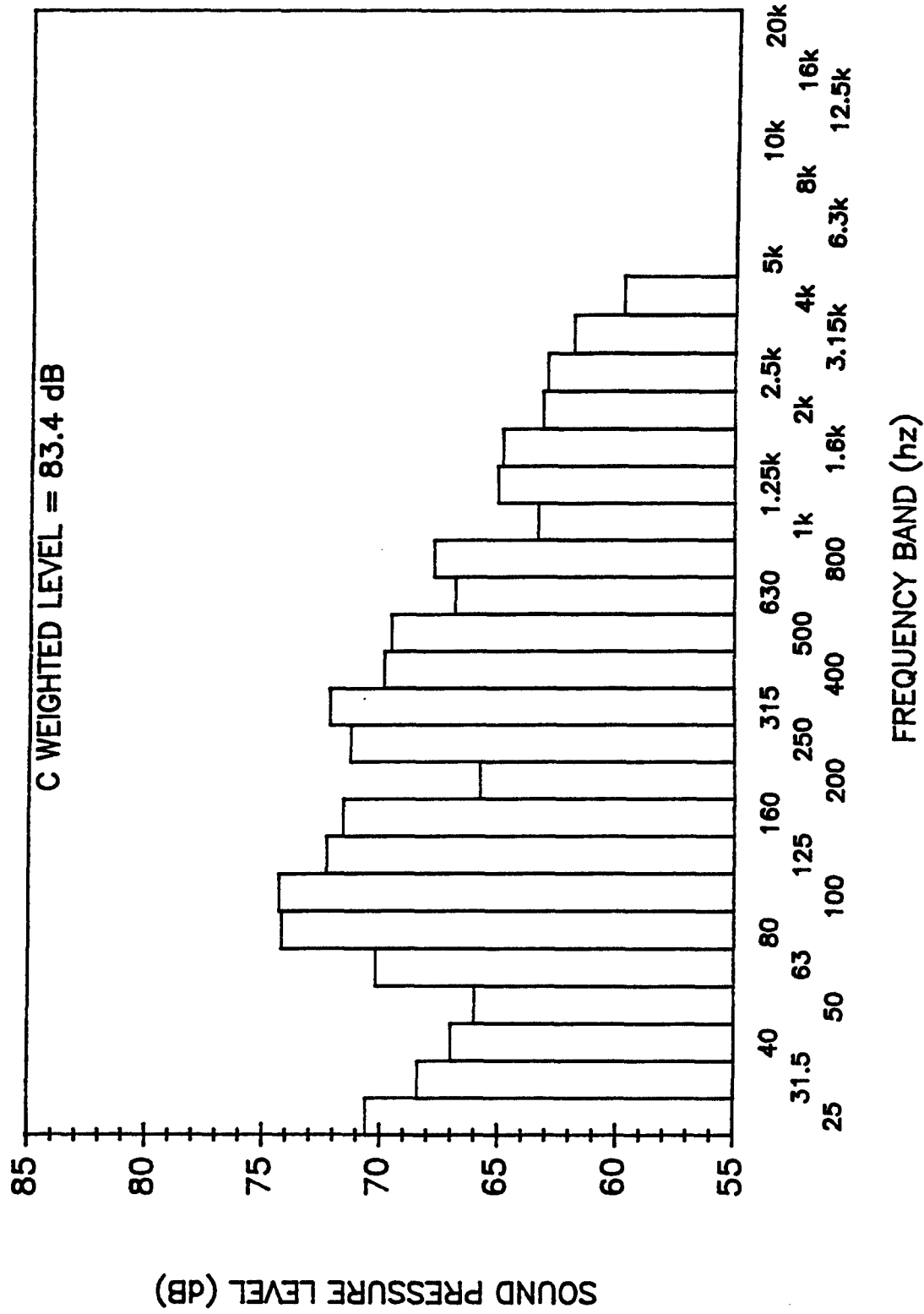
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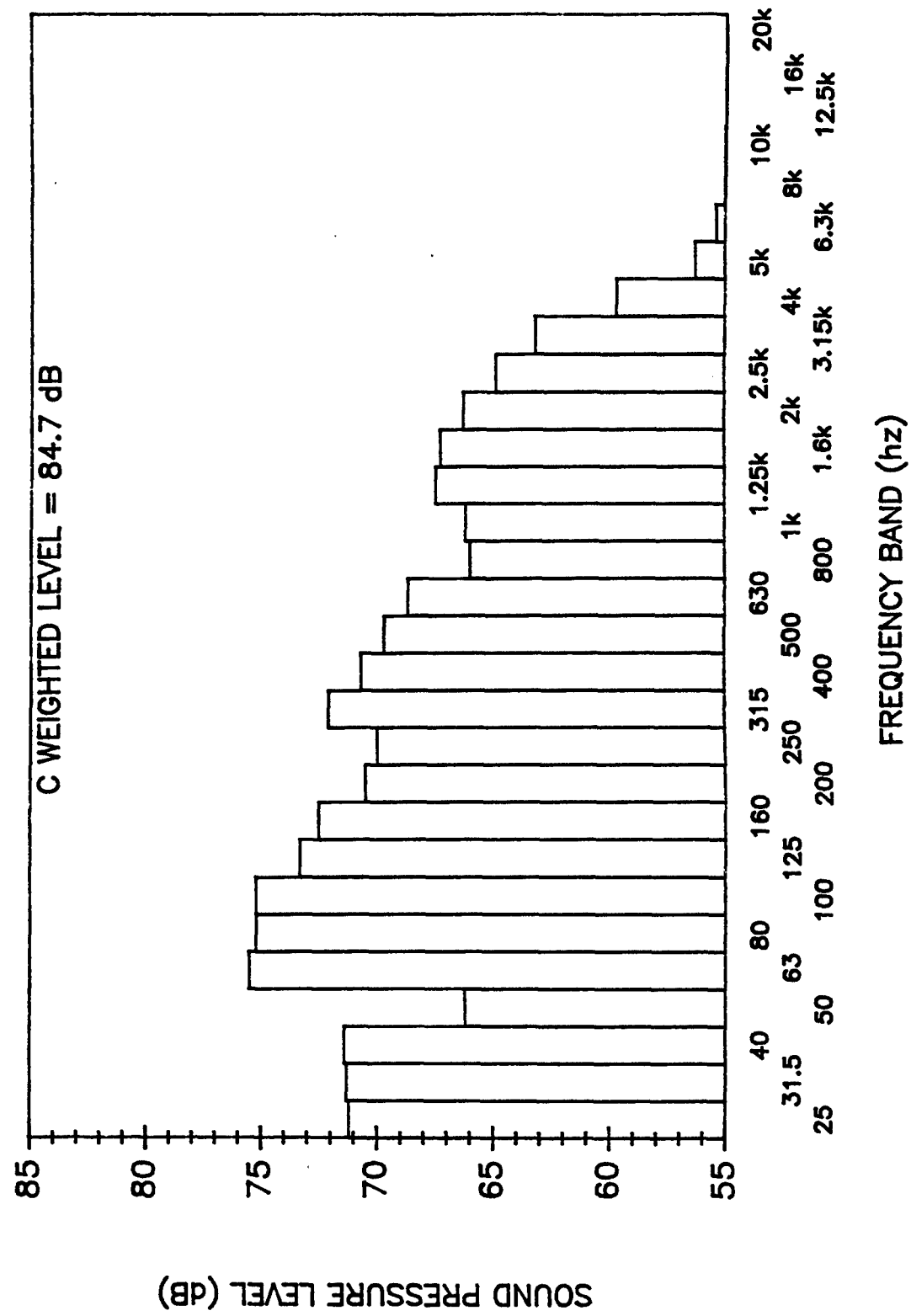
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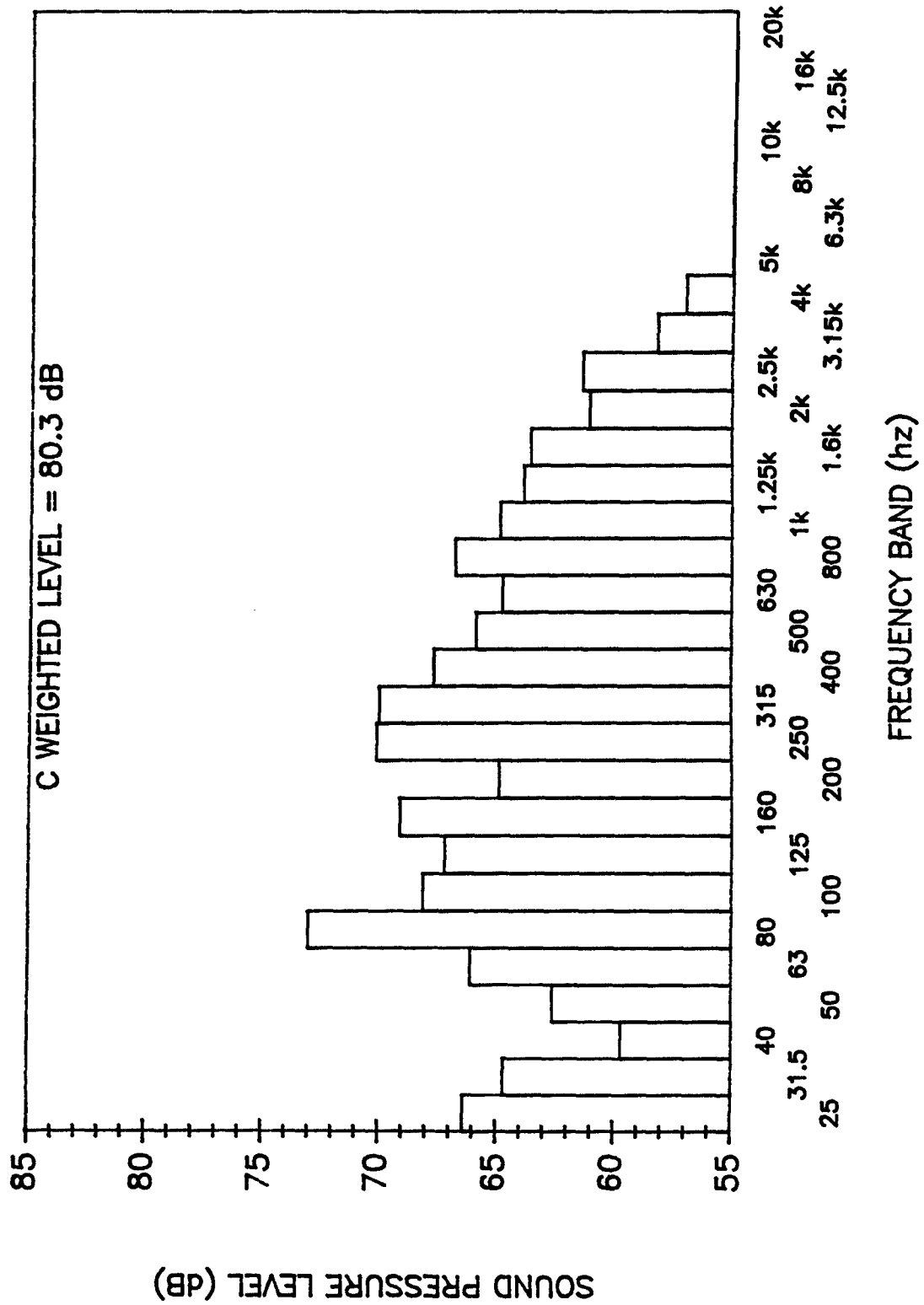
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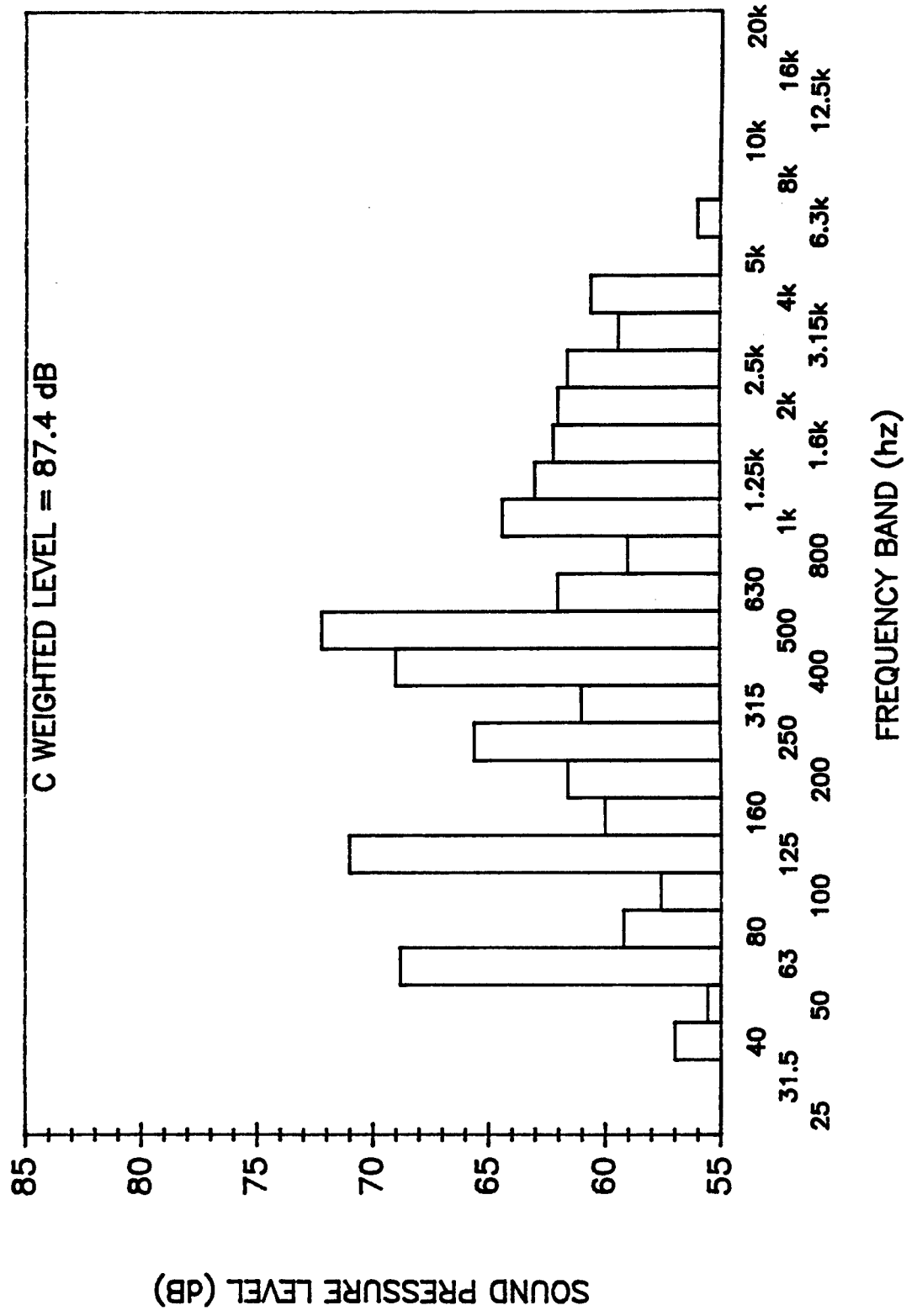
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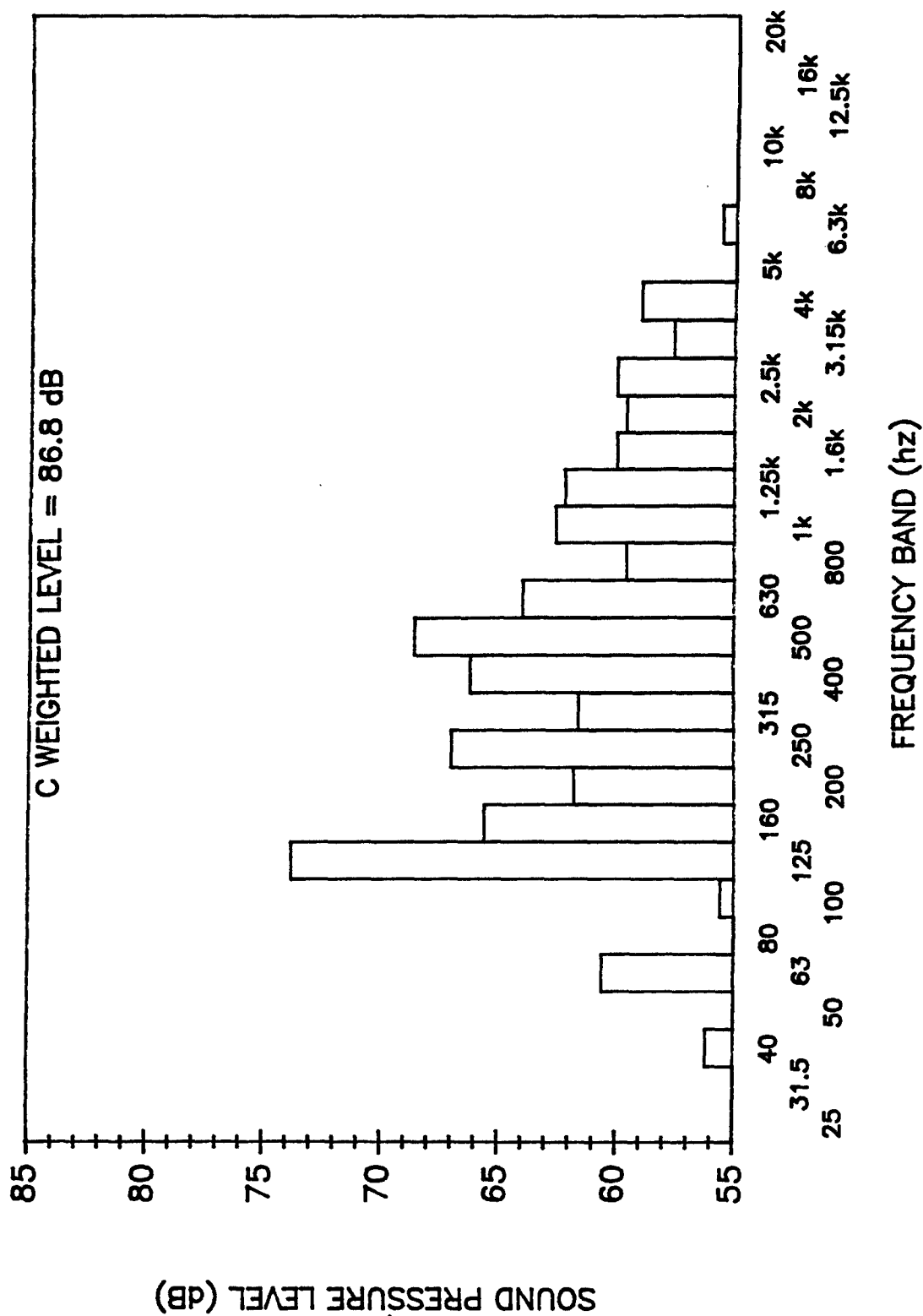
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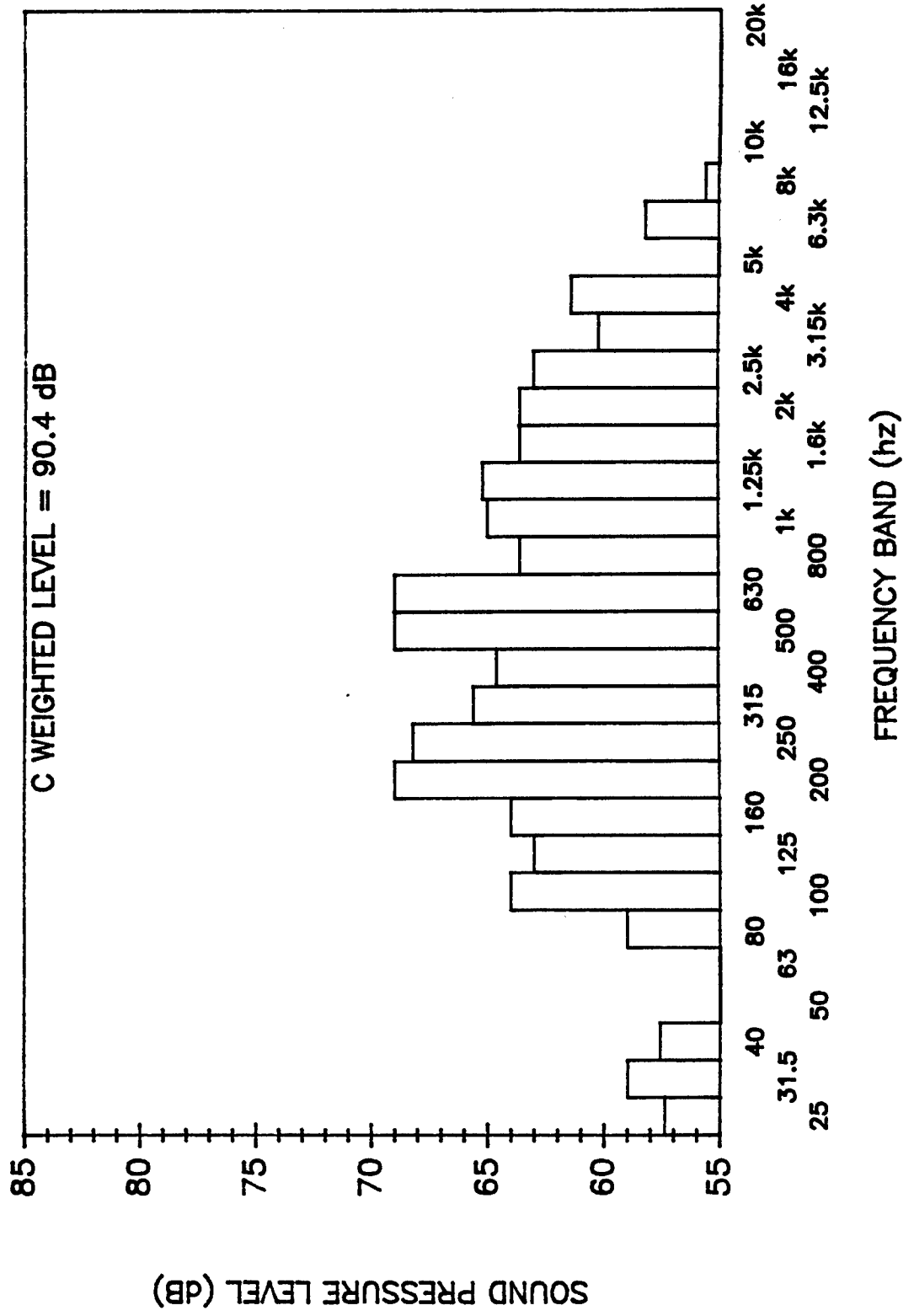
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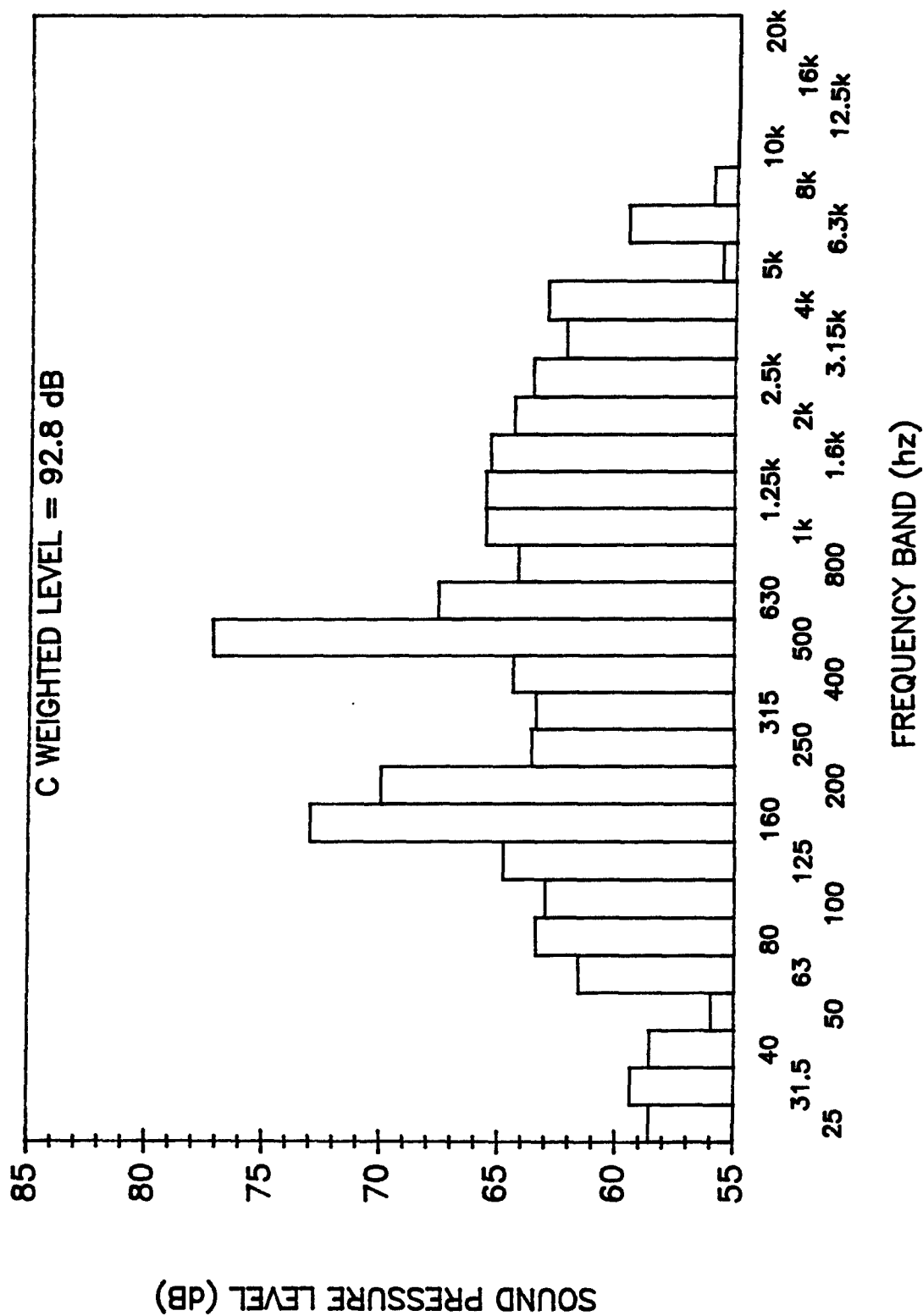


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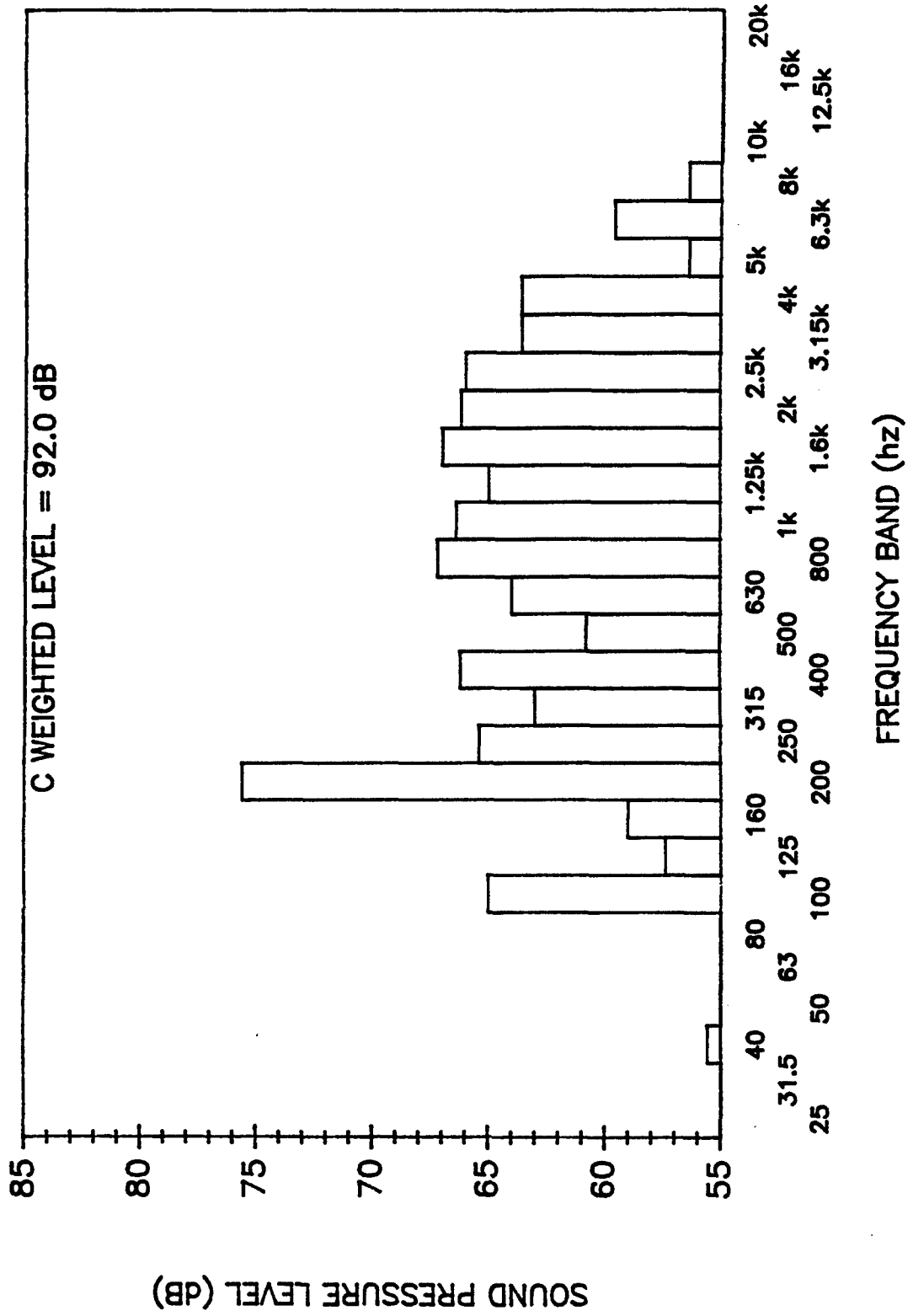




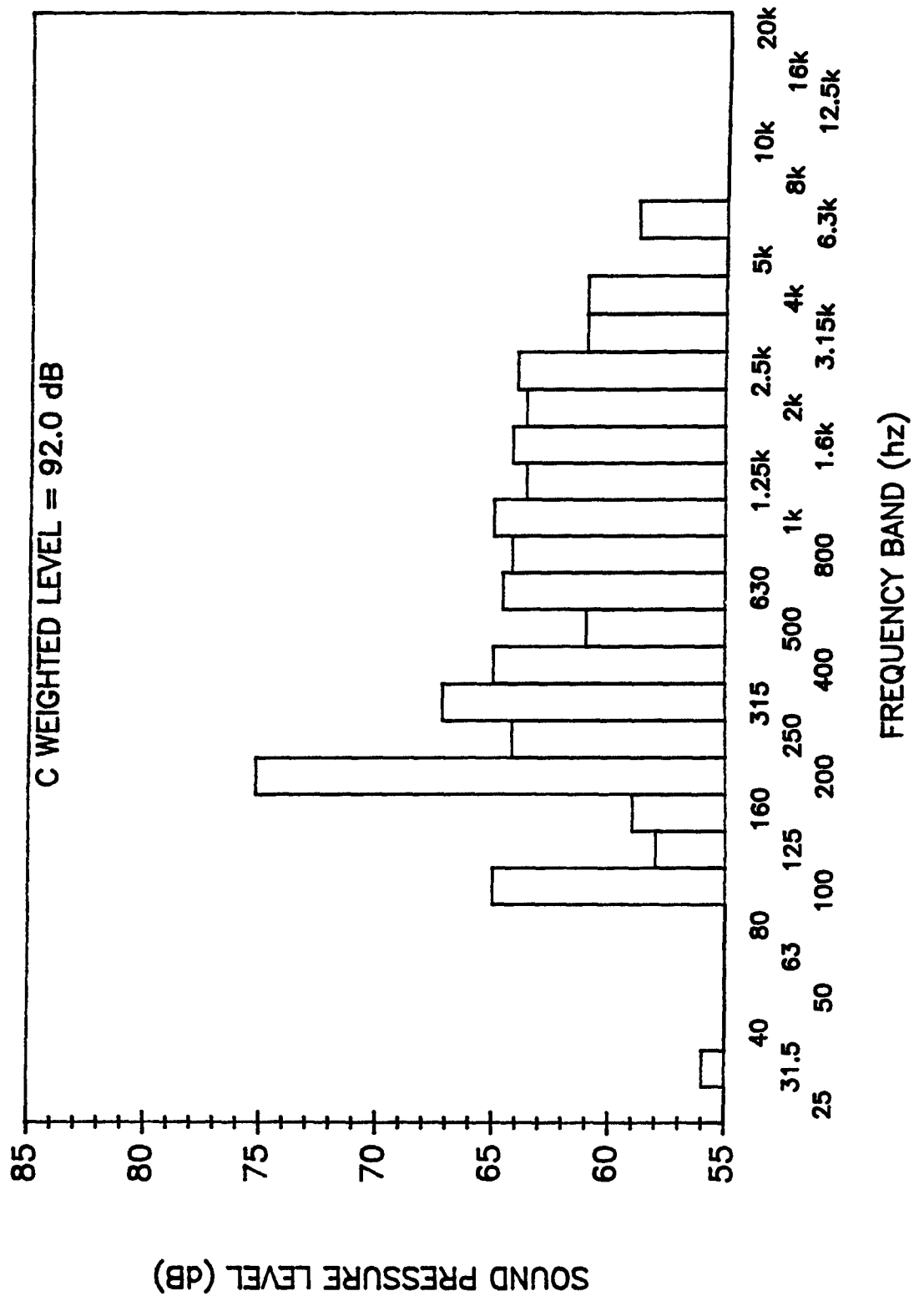
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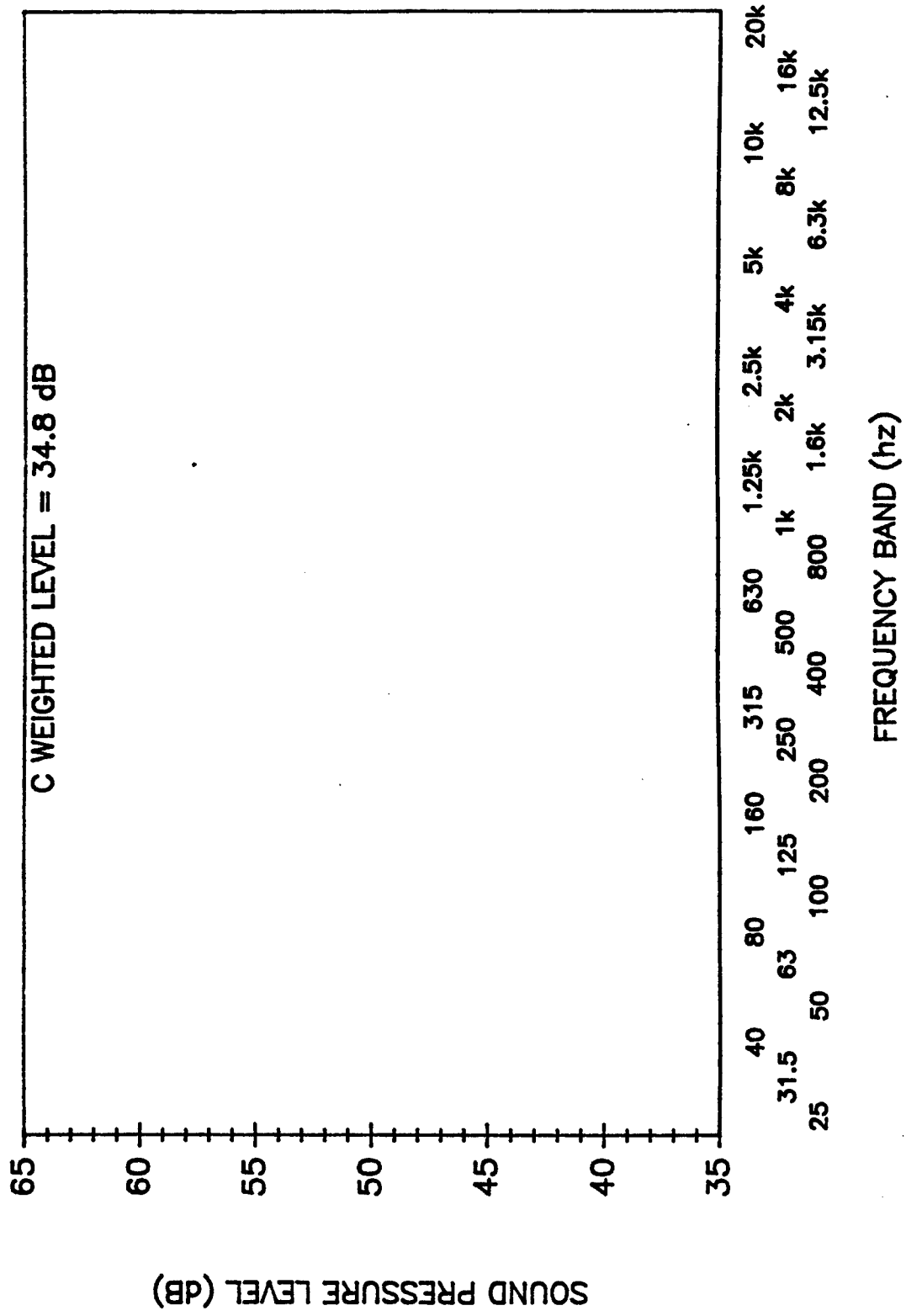
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YAMAHA ET400TRN SOUND PRESSURE LEVEL  
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YAMAHA ET400TRN SOUND PRESSURE LEVEL  
THIRD OCTAVE ANALYSIS - SLOW TIME CONSTANT  
AMBIENT POST-TEST AT THE INSTRUMENT 1 METER AWAY  
MARCH 15, 1991



YAMAHA ET400TRN SOUND PRESSURE LEVEL  
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